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COASTAL ENVIRONMENT, BATHYMETRY AND PHYSICAL OCEANOGRAPHY ALONG--ETC(U)
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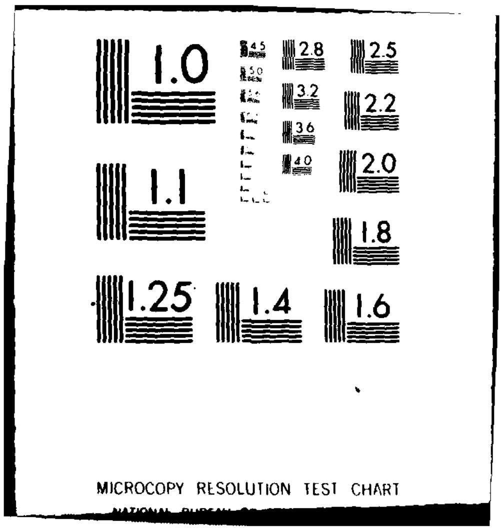
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Special Report 80-5

January 1980

COASTAL ENVIRONMENT, BATHYMETRY, AND PHYSICAL OCEANOGRAPHY ALONG THE BEAUFORT, CHUKCHI AND BERING SEAS

Lawrence W. Gatto

Prepared for
OFFICE OF MARINE GEOLOGY
U.S. GEOLOGICAL SURVEY
By
UNITED STATES ARMY
CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (9) Special Report 80-5	2. GOVT ACCESSION NO. AD-A084 281	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) COASTAL ENVIRONMENT, BATHYMETRY AND PHYSICAL OCEANOGRAPHY ALONG THE BEAUFORT, CHUKCHI AND BERING SEAS.		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) Lawrence W. Gatto		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Marine Geology U.S. Geological Survey Reston, Virginia 22092		12. REPORT DATE (11) January 1980
		13. NUMBER OF PAGES 360 (12) 360
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) (14) CRREL-SR-80-5		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Bathymetry	Geography
Beaufort Sea	Geology
Bering Sea	Marine geology
Chukchi Sea	Shores

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report compiles references, figures, and tables that are concerned with the coastal environment, bathymetry, and physical oceanography along the Beaufort, Chukchi, and Bering Seas. The text, intentionally minimized, describes the salient points with a minimum of detail. The extensive references and figures give direction to a reader seeking additional information.

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PREFACE

This report was prepared by Lawrence Gatto, Geologist, Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the Office of Marine Geology, U.S. Geological Survey.

The author expresses appreciation to Jerry Brown, Malcolm Mellor, Paul Sellmann and Ed Andreas for technical review of the manuscript and for several helpful suggestions, and to Eleanor Huke for assistance in preparing figures and illustrations.

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CONTENTS

INTRODUCTION

The U.S. Geological Survey contracted the USACRREL to prepare a review report assessing environmental factors affecting the stability of offshore structures in polar waters. The report was to address the conditions, processes, and forces present in polar areas, and the geotechnical factors that influence design and operation of offshore drilling platforms along the ice-affected portions of the Alaskan coast. The report also was to contain a digest of information that could be used by engineers and regulatory organizations during discussions and evaluations of future offshore oil lease sales.

The complete report addresses the following main topics: sea conditions, seabed conditions and structural foundations, horizontal, vertical, and inclined ice forces, mechanics of ice-breaking techniques, and icing on structures. Each main topic has three to six subtopics.

This report is the part of the complete review report that reviews existing data on the environment, bathymetry, and physical oceanography of the Alaskan coastal zone and continental shelf along the Beaufort, Chukchi, and Bering Seas (Fig. 1). Recommendations on data needs, future work, and suggested methods for obtaining the required new data are included.

The open literature was the source of the information presented. Privileged or classified information from petroleum or mining companies, or from government agencies, was not used. The open literature was not exhaustively explored however; only major sources were cited. Although

not specifically cited in the text of this report, there are many additional sources that can provide useful background information and more details on a specific topic. Some of these sources are given in the "additional references" sections.

Several maps and other bulky reference materials with useful data are not included in this report. They are referenced and can be easily obtained from the publishers.

The amount of text in this report has been intentionally minimized. Tables, diagrams, and figures were freely used in place of text to present the main points. A reader requiring additional details should refer to the original source.

Figures from different sources for the same parameter were included to illustrate differences in data interpretation. The differences may also reflect data variablity or changes in the parameter that occur seasonally.

Many new publications are being made available from the NOAA Outer Continental Shelf Environmental Assessment Program (OCSEAP). These are available in the open literature and in a series of OCSEAP publications. As part of OCSEAP, Dr. Michael Vigdorchik at INSTAAR, University of Colorado, Boulder, Colorado, has compiled, synthesized, and computerized much of the data acquired by OCSEAP investigators. His files should be an invaluable source of new, more detailed information on the coastal zone.

Many figures and tables shown in this compilation are from the Arctic Environmental Information and Data Center's "Alaska Regional Profiles," "Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska," and "Chukchi Sea: Bering Strait-Icy Cape." These excellent publications are especially useful.

BEAUFORT SEA

Coastal Environment

Geology

The coastline is crenulated and deeply embayed, especially west of the Canning River (3). En echelon islands make the general shape of the coast straight except at large embayments (Fig. 2). The general coastal geometry may not change for many years; promontories and points persist (3).

The Arctic Coastal Plain continues offshore onto the continental shelf with little break. Broad lobes of sediment extend kilometers offshore of river deltas, and barrier island chains enclose shallow lagoons with many shoals (1). The islands are frequently far offshore, with large lagoons between them and the mainland. These lagoons are exposed to more wave activity than the outer island shores because they are ice-free for more of the year.

The offshore islands have different sources (3). Islands at river mouths are emergent shoals of fine river sediment deposited at the outer fringes of the river deltas. Some islands are scattered tundra remnants separated from the mainland by erosion (1) and modified by currents and ice erosion (30). Some are constructional features similar to barrier chains (6).

The constructional islands are very mobile, migrating westward and landward 19-30 m/yr in the western chains and 3-7 m/yr in the central

and eastern chains. Some migrate southwesterly 4-7 m/yr. Passes between these islands are filling and new ones are developing. These constructional islands are frequently flooded during autumn storm surges. Ice-bonded permafrost can be found on the islands, particularly on the older more stable examples. (Sellmann, personal communication, 1979).

The mainland shores generally have narrow, low-lying beaches with backshore coastal bluffs typically 2-3 m high (7, 3). Few beaches exist. They are usually <20 m wide, tens of centimeters thick, and composed of gravel between the Canning River and Pt. McIntyre, and of sand farther west (1, 3). Beach material primarily results from bluff erosion but some sand and gravel come from submerged nearshore sites, reaching the beach through ice push (3, 7).

Slumping of coastal banks is common. There are scattered spits from points of land, and large rivers typically build broad deltas. Scattered emergent features suggest the coast is rising (1).

Some of the coastal geomorphology is a relict of a previous interstadial period approximately 120,000 years ago (3). Beach changes are currently caused by ice in the winter (8) and more normal processes in the summer. Four main types of coast (Fig. 3) have been defined and classified by relief (Fig. 4) (8). Additional relief and geomorphic information is available on the U.S.G.S. topographic maps of the area (Table 1).

Three types of offshore bars are found from Cape Lisburne to Demarcation Pt.: multiple parallel bars, with inner and outer systems,

long parallel bars in series attached to the shore on the updrift end, and shorter en echelon bars attached to the shore (25). Some of the last kind are migrating westward at 70 m/yr with sediment movements of 4×10^5 m^3/yr. The attached bars can produce shoreline undulations of horns and bays with amplitudes of 200 m and wavelengths of 4-5 km (Table 2).

Surficial geologic materials of the mainland coast east of Oliktok Pt. stem from alluvial and glacial outwash fans from the Brooks Range, or from sandy marine muds with foreign glacial pebbles, cobbles, or boulders of the Pleistocene Flaxman Formation (1, 3, 4, 31, 32, 33). West of Oliktok Pt. the fan material is underlain by compact stony muds of the Flaxman which extends out on the continental shelf under the sea floor (3).

West of the Colville River the unconsolidated marine sediments of the Quaternary Gubik formation lies unconformably on Cretaceous marine shales, mudstones, and sandstones which dip northward from the foothills to the continental shelf (4). The Gubik outcrops at the cliffs southwest of Pt. Barrow.

Geologic lineaments with 40° and 300° azimuths control the coastal configuration, with the Chukchi Sea coast parallel to the 40° set and the Beaufort Sea coast parallel to the 300° set (5). The lineaments may influence the orientation of the offshore islands.

Except near Barter Island, most of the Beaufort Sea coast is aseismic (Fig. 5 and 6) (8, 17). No seismic activity >6.0 on the Richter scale has occurred from 1955-1964 (19).

Coastal Processes

Four oceanographic regimes are found along this coast. The nearshore regime has shallow lagoons and embayments (wind-driven estuaries in the summer). The inner shelf, bounded by the 10 and the 50-m isobaths is probably wind-driven in the summer; processes here are poorly understood. The outer shelf extends to the shelf break, is very active, and is occupied in part by Bering Sea water. The Beaufort Gyre is part of the large-scale Arctic Ocean ciculation (16).

There are three periods characterized by different processes that dominate the coastal morphology: freeze-up, breakup, and open water (26). In autumn the beaches freeze and become ice-covered, then snow-covered (3); minor ice erosion occurs (26). By early winter beaches are protected until early spring. Ice push changes nearshore bathymetry during this interval. Normal coastal processes are limited when the ice pack is on shore (8).

By early summer ice begins to break up and the low coastal bluffs thaw. Mudflows ooze onto beaches or residual snowbanks (3). Sea ice breakup begins in late May, river breakup, in May or June (26).

From late summer to early autumn (2-4 months), beaches thaw 1.5-3 m (1) and erosion increases as low pressure cells crossing Alaska produce higher winds, currents, and sea levels, and increased wave energy in open water (26). Bars are frequently breached by river breakup and storms (26). Coastal transport increases and the ice pack sometimes hits the outer beaches (3).

Tides have minimal effect on normal shoreline processes. Wind-generated waves and currents dominate (4, 10).

Littoral sediment drift is westward on the inner shelf (12) east of Pt. Barrow, but local reversals occur due to wave refraction and winds (3, 17). Net effective longshore transport at Barrow is northeast (4). Normal average yearly northeasterly transport west of Pt. Barrow is 7640 m^3. Normal average southeasterly movement east of Pt. Barrow is 7260 m^3. More than 153,000 m^3 were moved during the 3 October 1963 storm (27). Estimates for the amount of shelf transport in the summer and autumn 1972 are 10,000 m^3 at Pingok Island and 5,000 m^3 at Maguire Island (3).

Sediment primarily comes from the rivers and coastal erosion (20). The amount of sediment transported is small due to low wave energy and the short season (3). Two littoral transport cells, usually <10 km wide, have been reported along the mainland (3). A small amount of sediment is transported along the beaches (17).

Coastal erosion rates are high, approximately 10 times higher than those along the Chukchi Sea coast (Fig. 7) (3, 17). Coastal erosion processes are augmented by thermokarst collapses and thermal erosion, and are most active in late summer and autumn (3, 17). The thermal erosion is followed by bank collapse and, where beaches are absent, rapid removal of collapsed material (1).

The erosion rates along the coast vary with bluff composition, being greatest in silt banks and least in sand and gravel bluffs (1). Exposure to wave action and nearshore morphology also affect erosion rates.

Annual erosion rates vary, based on the time of ice breakup, the size of open water areas, and the occurrence of late summer-autumn storms (3). Normal erosion and transport cease for nine months when beaches are frozen (1). The ice pack moving nearshore dampens waves and reduces erosion.

Some average erosion rates are from the Mackenzie River to Demarcation Pt., 2.5 m/yr; from Demarcation Pt. to the Colville River, 1.6 m/yr; at Oliktok Pt., 11 m measured during a two week period; on Pingok Island, 1.5 m/yr; on Flaxman Island, 3.5 m/yr (on sea and lagoon side); from Harrison Bay to Barrow, 4.7 m/yr; at Drew Pt. and Cape Simpson, 30 m/yr (3, 28); and, for the period between 1948 and 1969, 58 m at NARL airport and 68 m along the shoreline southwest of Pt. Barrow (1). Coastal retreat probably occurs throughout the region from Pt. Barrow to the Mackenzie River (1).

Mainland shores next to lagoons retreat more slowly than open coasts. Erosion rates on offshore islands tend to be similar on both the sea and the lagoon sides (3). The island groups are not simple barrier chains. Most islands are lag deposits from their own sand and gravel sources. Island passes that act as barriers to littoral sediment transport are drowned river distributaries, low areas between Pleistocene hillocks, or storm breaches (3).

Progradation occurs at large river mouths as deltas are deposited slowly; for example, 2 m has deposited in the last 26 years at the Colville River (3). Ice transport of sediment in the littoral zone consititues 1% to 10% of the total sediment transport (4). Ice modifies

the coast by bottom scouring, ice push, and sediment rafting (8, 12). Details regarding site specific processes are available from the Outer Continental Shelf Environmental Assessment Program report series.

Vegetation

The detailed unit descriptions and the distribution of the vegetation types from the U.S. border to Pt. Barrow are available in references 1 and 34. Wet tundra predominates from the U.S.-Canadian border to Barrow. However, moist tundra also occurs along the coast east of the Canning River delta.

Soils

The detailed unit descriptions and the distribution of soil types along the coast are available in reference 35. Maps two and three cover the coast from the U.S.-Canadian border to Pt. Barrow. Reference 35 defines major land resource areas that border the coastline. Each area is characterized by a unique pattern of topography, climate, vegetation, and soils. The Arctic Coastal Plain is the only resource area from the U.S. border to Pt. Barrow.

Land Use

Detailed descriptions and the distribution of land use along the coast are given in reference 1. Occasional and intermittent uses predominate. They include recreation, sport hunting and fishing, subsistence, seasonal residence and mineral and petroleum development and exploration. Of these, subsistence use predominates.

The small communities or villages are scattered. They include

concentrated residential areas with limited services and industrial areas. Population centers are principally along the coast at sites historically used at subsistence levels. Minor government installations and churches caused permanent occupations at these sites.

The remaining categories are: military installations, scattered; industrial development of petroleum, in the Prudhoe Bay area; the Arctic National Wildlife Range, from the U.S. border to the Canning River delta; the National Petroleum Reserve - Alaska, from the Colville River to Icy Cape in the Chukchi Sea.

Bathymetry

Generalized bathymetry is shown in Figures 8, 9, and 10. Detailed bathymetric data are not available for the entire coast (20). Some data are available for specific locations. Reference 7 gives bathymetric profiles taken in 1975.

The continental shelf is essentially flat with microrelief caused by ice gouging in the nearshore zone (1, 7, 8, 12, 14). The shelf varies from 40 to 48 km wide in the east to 76 to 97 km in the west (14, 20, 24); the shelf break is usually at depths of 50-70 m (20). The average slope of the shelf is 0.5 m/km with a maximum of 1.3 m/km (14). Three submarine canyons cross the shelf; the largest is off Pt. Barrow (30). Beyond the shelf break the continental margin drops steeply to 3940 m in the Beaufort Deep (1, 30).

En echelon offshore bars extend laterally 400-600 m seaward from the shore and migrate west at 70 m/yr. Bars are 2-10 km long near

Leavitt and Pingok Islands (13). Other shoals have migrated landward 100-400 m in 25 years (7).

Submerged ridges are prominent northeast of Pingok Island. East of Prudhoe Bay, the Reindeer-Cross Island Ridge extends to Narwhal Island (14).

Additional bathymetric data on the nearshore area may be obtained from the National Ocean Survey (NOS). Harbor charts of the nearshore area from Pt. Hope to Pt. Barrow are available at a scale of 1:50,000. These charts contain selected, individual soundings corrected to mean lower low water (MLLW).

The original hydrographic surveys of this area are also available as boat sheets from Atanik (north of Wainwright) to Naokok Pass. They were originally prepared at a scale of 1:40,000 but have been photo-reduced to a scale of approximately 1:80,000 for convenience. Depths are in feet, beginning the 6-ft contour and terminating at the 60-ft contour. Data are MLLW.

A complete list of the NOS navigation charts is available in NOS Nautical Chart Catalogue No. 3, Alaska. Detailed 1:50,000 scale charts are available for the Beaufort Sea coast and the Chukchi Sea coast from Pt. Barrow to Pt. Hope. Charts for the coast from Bristol Bay to Cape Wrangell vary in scale from 1:5,000 to 1:350,000. Chart scales from Pt. Hope to Bristol Bay vary from 1:1,534,076 to 1:2,500.

Physical Oceanography

Tides

Virtually no work has been done on tides (16). The limited data show that astronomical tides are usually mixed diurnal or semidiurnal (Fig. 11), and are weak and unpredictable (8, 16, 22). Mean tide range at Pt. Barrow is 10-30 cm, usually 15 cm (3, 4, 8, 16), neap is 7.6 cm, spring, 15.2 cm. The princial lunar tide (M_2) at Barrow is 4.7 cm (16). Changes in barometric pressure and wind direction can cause larger sea level fluctuations than the tides (3) (Fig. 12).

The tide wave approaches the Beaufort Sea shelf from the north with little phase change from Pt. Barrow to Demarcation Pt. (16). Tides are similar west of Pt. Barrow, becoming unpredictable to the east (8). Most Alaskan tides are quite variable with very different extremes and averages (Fig. 13) (24).

Storm Surges and Water Levels

Storm surge is a rise of the water level caused by onshore wind stress and a drop in atmospheric pressure (8, 36). Factors that influence storm surge are water transport by waves, the earth's rotation, rainfall coastline configuration, changed in the water level and bathymetry (2). Combinations of these phenomena can produce positive or negative changes in the water level. Changes in sea level of 1.4 m can occur in a few days (1).

Figure 14 shows storm surge occurrences since 1963. Other, minor, surges have occurred. The likelihood of surges along this coast usually

increases during periods from July through October when there is little or no sea ice (2) and the air temperature is colder than that of the water. Frequent strong northwest winds in conjunction with barometric lows cause storm surges 3 m above normal sea level with waves of up to 6 m (3). At Barrow Village westerly winds increase sea level, easterlies reduce it (8). Surges and wave heights are usually larger in the Chukchi Sea than in in the Beaufort because of the Chukchi Sea's longer fetches.

Surges cause the most important changes in the level of the Beaufort Sea (16). One-meter changes are not uncommon and some may exceed two meters (15). The largest surges occur in September and October, during fall polar storms (8). Winter surges are common but usually smaller than those of the summer. Negative surges of 1 m or less are frequent in the winter (16).

The effects of surges vary along the coast (16), but they can cause flooding, increased erosion (15), and other major changes (4). The worst recorded storm at Pt. Barrow produced westerly winds of 88-120 km/hr, a storm surge of 3.3-3.6 m and 3-m waves, as well as a surge of 1.7 m at Barter Island (4, 8). The storm resulted in massive erosion and major changes in the coastal morphology (4).

Waves

Wave energy is small because the potential fetch is limited by the ice pack which never is more than some tens of kilometers offshore (3). There is no significant wave activity from November to May when the Chukchi and Beaufort Seas are ice covered (2, 17). The pack ice also limits waves in the summer (8). Largest waves recorded are > 9 m; near Pt. Barrow, 6-m waves were recorded in 1951 (8). Wave heights of $\geq$ 6 m during other months occur < 1% of the time (2). Wave heights are < 1 m 90% of the time. Hazardous and nonhazardous wave height thresholds are shown in Figures 15-34.

Waves along the coast usually come from the northeast (5, 6, 8), which is the dominant wind direction. Easterly winds dominate in the summer, but westerlies and northerlies occasionally move the pack ice shoreward in the summer (20). Near Pt. Barrow, waves usually approach from the north and the west (4). Swells from 1.6 - 2 m occur when easterly winds persist in the late summer and early fall (1). Tables 3-7 show wave data for the coast from Peard Bay to the east side of Harrison Bay (marine area 6) between 1 July and 20 November and from Harrison Bay to the U.S.-Canadian Border (marine areas 5, 4) between 11 July and 31 October. Figures 15-34 give seasonal wave data for three areas along the coast. These data are complied in Figure 35.

Currents

Tidal currents are a small component of the coastal currents (10, 16). The diurnal and semi-diurnal tidal currents are usually $\leq$ 1

cm/s (16). The currents can be 25 cm/s in tidal passages that are restricted by ice cover (16). Tidal currents can be 5 cm/s on the outer shelf (16). Currents caused by phenomena other than tides are more important along this cosat than are tidal currents.

General circulation patterns are shown in Figures 36-38. Figures 39-41 show the currents along the Beaufort Sea coast, and Figures 42-44, currents in the Beaufort/Chuckchi Sea area. Details are evaluated in the source references.

Large-scale, generalized regional circulation shows similar patterns in the summer and the winter (Fig. 36 and 37)(24). The circulation is dominated by the clockwise flow in the Arctic basin (1) known as the Beaufort Gyre. This gyre is offshore from the continental shelf, flows generally westward with a mean velocity of 2 cm/s at the surface in the center of the gyre. The gyre's velocity is 5-10 cm/s near Pt. Barrow, and it may have a counter-flow to the northwest of Pt. Barrow along the Chukchi Rise (16). Easterly and offshore winds produce this southward counter-current in late summer and early fall (1).

Some Pacific Ocean water enters the Bering Sea, producing a net northward flow through the Bering Strait to the Arctic Ocean. There is a weak westward current along the Beaufort Sea coast to Pt. Barrow (24). This current flows at 1-2 km/day (1). Currents farther offshore flow 2-4 km/day (30).

Nearshore currents are generally weak, mostly wind-driven, variable, reversible, and controlled by bottom topography (1, 10, 30). Winds are

crucial to the nearshore and shelf circulation (16). Local winds cause current fluctuations, but not all wind variations alter the currents (29). Winter flow is predominantly northward, summer flow has significant reversals (10). The nearshore motion slows in the winter because of the ice pack, which also limits the waves and the tidal range (8, 16). Current velocity east of Pt. Barrow is usually < 50 cm/s; west of Pt. Barrow, it is 150-200 cm/s (8).

There are two modes of deep circulation on the Beaufort Sea shelf: eastward flow of Bering Sea water that follows the shelf break and is steered by the bottom contours, and westward flow of cold dense water which sometimes wells up onto the shelf (9).

Many factors complicate circulation on the shelf (19). Along the inner shelf, westward flow predominates due to prevailing east winds (9, 16); flow velocity is typically 15 cm/s in summer. The fastest surface currents have velocities of > 20 cm/s southwest of Pt. Barrow (29). Rapid changes and current reversals occur with wind changes (16, 20). Winter velocity measurements 10 m below fast ice show velocities slower than 10 cm/s, and usually slower than 5 cm/s, with a mean of 0.1-0.3 cm/s (16). There is some eastward flow from the Chukchi Sea over the inner shelf at dpeths of 110 to 140 m. Currents vary from 40 cm/s to 100 cm/s (20).

The outer shelf is highly energetic. The summer temperature maximum is subsurface due to Bering Sea water intrusion. The outer shelf has upwelling, strong stratification in the south after freeze-up, and

reduced stratification in the winter. In August 1972 current velocities at 25 m showed a strong eastward flow with a velocity of 10-60 cm/s. The mean velocity was 60.8 cm/s, with reversals (16, 29). From 100 - 225 m velocities vary from 56 cm/s eastward to 26 cm/s westward (May-September 1976) with large low frequency oscillations (16).

The Beaufort Gyre becomes more prominent offshore. A clockwise westward flow of arctic water at a velocity of 4 cm/s occurs from 9 - 200 m (11, 20). Atlantic and bottom water flow at < 3 cm/s deeper than 200 m (Fig. 46). Currents of 45 cm/sec occasionally occur at the pycnocline for several days before disappearing (11). Upwelling associated with clockwise westward gyre flow occurs approximately 125 m from shore (20).

Temperature and Salinity Distributions and Water Masses

General patterns of temperature and salinity distribution are shown in Figures 47-73. Sea ice reduces the sea's moderating effect on air temperature (24). The patterns imply a northward flowing current through the Bering Strait. Summer warming is pronounced in Norton and Kotzebue Sounds. Summer temperatures in the Beaufort are about 0°C due to ice effects (24).

Related surface density is shown in Figure 51. Sea surface temperature extremes and mean sea surface temperatures are shown in Figures 52-71. Figure 73 shows the average August sea surface temperatures.

Nearshore temperatures and salinity structures are highly variable during the open water period (10). After breakup, strong stratification exists, with a warm, fresh surface layer 4 m thick (from runoff and ice

melt) over homogeneous cold saline water (the remnant of pre-ice cover water). The pycnocline is destroyed by turbulent mixing after breakup. For the balance rest of the ice-free season, variations in the water structure are caused meteorological tides (10). By the end of July strong halocline has formed.

Temperature and salinity are highly variable near shore and in the lagoons and bays (16). Summer variations on the inner shelf, are large gradually decreasing after freeze-up. By mid-winter, the water is at the freezing point for its salinity (30-32^{o}/oo) remaining at that temperature until early or mid-summer (16).

Winter temperatures below the ice pack are -1 to -2°C, while in the summer they are $\geq$ 0°C (20). Fresh water input is important along the coast where warm, low salinity water moves out over colder, more saline water (20). In summer, the salinity ranges from 10-20^{o}/oo. In winter, the salinity increases because of decreased less runoff concentration of brine as ice forms. Salinites range from 30-40^{o}/oo under ice in winter (20). Ice melt produces a surface layer ($\geq$ 9 m deep) of cooler ($\approx$ -1.8°C), less saline (< 30^{o}/oo) water. Freezing produces a colder ($\leq$ -1.8°C), more saline ($\geq$ 31^{o}/oo) surface layer (20).

The following water masses occur in the Beaufort Sea. Arctic water from 0-200 m is low salinity and colder (averages -1.5°C)(11). The surface layer (100 m thick) shows seasonal changes in temperature and salinity in response to freezeing and thawing of the ice pack. It is the coldest water mass. Temperatures vay from -1.4°C at the end of summer to -1.7°C at the end of winter. Its salinity varies from 28-

32^{o}/oo (30) (Fig. 72). Below the surface layer, the temperature and salinity have less annual variaton.

Pacific and Atlantic water lies below the Arctic water. The Pacific water is an interlayer of water that is warmer than the Arctic water, having come from the Bering Sea (30). Atlantic water at depths of 200-900 m has high salinity and is warmest (0-1°C)(11, 30). Salinity is uniform with depth, 34.9-35.0^{o}/oo (30). Bottom water lies below 900 m, has uniform salinities from 0 to 34.9^{o}/oo, and decreases in temperature with depth to -0.40°C (30).

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CHUKCHI SEA*

Coastal Environment

Geology

The coast from Wainwright to Pt. Belcher (Fig. 74) is exposed to the open ocean. Wave erosion and minor deposition take place along this coast (12). Sea cliffs are cut into bedrock and ice-rich sediment and can be eroding significantly, but maybe in near-equilibrium. From Pt. Barrow to Peard Bay, cliffs have Gubik sediments over Cretaceous clays and interbedded sandstones (3, 14). Narrow gravel beaches have formed at the base of many of the sea cliffs. Coastline topographic relief is predominantly moderate, < 2-5 m, but many locations have high relief, 5-8 m (12, 17). From Pt. Barrow to Peard Bay, some cliffs are > 18 m high, but most are around 10 m (3, 14).

A barrier island coast predominates from Wainwright to the mouth of the Koocheak River. The islands protect the mainland from waves, ice, and currents. Several rivers empty along this reach so river deposition is dominant. Deltas with dune fields are common. Gravel spits cut off many river mouths and some river mouths appear as drowned estuaries, suggesting a rise in the sea level or subsidence of the land (1). Wave erosion is active just north of Koocheak River. Relief is generally < 4 m but varies (12).

From the Koocheak River to Cape Lisburne, the coast is erosional. No major rivers empty along this reach. Wave stress is not too high. The northern part of this reach has a straight shoreline with sheer sea

* Some figures and tables in the Beaufort Sea section have information on the Chukchi Sea, also. Refer to them for additional details.

cliffs and bluffs cut to the bedrock. Relief is generally several hundred feet, but scattered locations have less relief.

The coast from Cape Lisburne to Cape Thompson is bounded by a wall of high rocky sea cliffs broken by Pt. Hope. Pt. Hope was deposited by converging local currents. Most of this reach is retreating and has very high relief, generally > 8 m, occasionally up to 100 m (1, 12).

From Cape Thompson to Cape Krusenstern, an erosional coast is interpersed with a few lagoons and short barrier beaches. Elsewhere, low cliffs back narrow beaches. There are scattered high cliffs.

The coast from Cape Krusenstern to Cape Espenberg borders a shallow embayment and has little relief. There is a delta shore on the east coast and discontinuous rolling hills and lowlands on the south coast (1). Lagoons and barrier islands dominate the coast from Cape Espenberg to Cape Prince of Wales. No large rivers enter this coast. Material for the barrier islands was probably transported through the Bering Strait by longshore currents (12).

Four earthquake epicenters > 6.0 on the Richter scale occurred along Chuukchi Sea coast between 1955 and 1964 (6). Generally, less erosion takes place along the Chukchi Sea than along the Beaufort Sea. Storms greatly affect the erosion rates (14).

Coastal Processes

The major means of sediment transport along the coast is the current that carries Yukon River sediment from the Bearing Sea north

through the Bearing Strait (1, 4, 7). Very little sediment gets into the littoral system from the coastal rivers (7). Some of the littoral sediment is lost down the Herald Canyon (7). The Kobuk and Noatak Rivers are major sediment sourcees for Kotzebue Sound.

Sea ice profoundly affects the normal coastal processes (6). Normal erosion and sediment transport cease for the nine months of the winter freeze (1). The ice pack covers the sea and the beaches are frozen, but minor ice rafting of sediment does occur (7).

As the ice recedes and beaches thaw to 1.5-3 m in the summer, normal erosion begins (1) (Fig. 75). Usually erosion and deposition processes remain steady with sudden changes resulting from storms (1). Summer erosion is a major problem along the cliffs, especially near Cape Thompson (1). Pt. Hope is receding on the north side and accreting on the south side, with a net wouthward migration of about 3 m/yr (1).

Vegetation

The detailed unit descriptions and the distribution of the vegetation types from Pt. Barrow to the Bering Strait are available in references 1 and 16. Moist tundra predominates from Pt. Barrow to Cape Lisburne and is intermittent from Ipnot to Goodhope Bay. Alpine tundra and barren ground occur in the Cape Lisburne area, frequently around the other Capes, along the south coast from Pt. Hope to Talikoot, and along the northwest shore of Seward Peninsula. Only a small stretch of wet tundra is found in the Pt. Hope area north of Tuckfield. Moist tundra is intermittent along the rest of the coast. Upland spruce and hardwood

forests occur along the north shore of Hotham Inlet.

Soils

The detailed unit descriptions and the distribution of the soil types along this coast are available in reference 20. The map sheets that cover the coast from Pt. Barrow to the Bering Strait are 1, 4, 7, and 8. The major land resources areas that border this coast are the Arctic Coastal Plain from Pt. Barrow to north of Cape Beaufort, the Western Alaska Coastal Plains and Deltas from Hotham Inlet to Kiwalik (the delta of the Kobuk and Selawik Rivers), and the Norton Sound Highlands from Kiwalik to the Bering Strait.

Land Use

Detailed descriptions and the distribution of land uses along the coast are given in reference 1. Occasional and intermittent use predominates, followed by scattered small communities and villages, military installations, and the urban development at Pt. Barrow and Kotzebue. Urban development comprises a mix of commercial, industrial, and residential land uses. Grazing dominates the southern shore of Kotzebue Sound and the northwest shore of Seward Peninsula. The Chamisso National Wildlife Refuge is on Chamisso Island.

Bathymetry

The Chukchi Sea shelf is broad, flat, featureless, and extends hundreds of kilometers offshore (Fig. 76). The shelf is a continental platform joining Siberia and Alaska (6, 7, 12, 16), composed of a

peneplain-like remnant with low relief and relict and residual sediments. The microrelief may be due to drowned Pleistocene drainage systems and ice gouging (17). Detailed bathymetry is not well known.

Depths are shallow and average 45-55 m (1, 17). Maximum depth is 64 m, deeper at the north edge near the Arctic Ocean (7). Generally, depths are 40 m 50-100 km offshore (Fig. 77). The large coastal bays, Kolyuchin (in Siberia) and Kotzebue Sound, are < 20 m deep (17). Herald Shoal is 13 m deep and is located due north of the Bering Strait (Fig. 78) (17).

The shelf along the northwest Alaskan coast drops off faster and is deeper at a given offshore distance than most coastal areas along the Beaufort Sea (7). Shelf slopes are gentle, from 3 m/km to nearly flat (1) except southwest of Pt. Hope where the shelf is relatively steep and is cut by the Hope Submarine Valley (12). Herald Canyon begins at 70° N and runs north along the 175° W meridian to the continental margin. Barrow Canyon is 150 km west of Pt. Barrow (17).

Depths plunge from 44 m in the Bering Strait to 62 m north of Wainwright (12). The sea floor near Diomede Islands and Fairway Rock rises rapidly, forming cone-shaped island promontories. Nearshore depths are probably maintained by currents and altered by ice gouging (12). Strong north-flowing currents through the Bering Strait probably scour the sea floor locally (12).

Ice scouring of the shelf is not extensive (7) but it changes local bathymetry. Other nearshore changes are caused by summer storm waves

which shift shallow shelf sands and sand bars. Little change occurs in deeper water (12).

National Ocean Survey (NOS) charts are available for the Chukchi Sea. Two detailed bathymetric maps of the Bering Strait are also available from NOS. These maps are in two or three colors, contoured at two-meter intervals corrected to MLLW, and are at a scale of 1:250,000. A generalized bathymetry of the southeastern Chukchi Sea is also available in Creager and McManus (1966)(see Appendix B).

Physical Oceanography

Tides

Tide range averages $\simeq$ .3 m (6, 7, 16, 17) and is larger than that in the Beaufort Sea (1). The effects of lunar tides on the water level are minor compared to the effects of wind and changes in atmospheric pressure (12, 16). The maximum change is > 3 m in six days and is probably due to meteorologic conditions (7). The ice cover slows the arrival and decreases the amplitudes of the tides (16).

The tidal wave enters the Chukchi Sea from the North Atlantic Ocean via the Arctic Ocean, so the tides have the characteristic North Atlantic semi-duirnal form (1, 12, 17). The tidal wave moves north to south and is amplified in shoaling water; mean tidal range at Kiwalik and Kotzebue Sound is 0.6-0.8 m (12).

Storm Surges and Water Levels

The Chukchi Sea coast has large storm surges due to the large fetch and the gently sloping and relatively flat bottom (1, 2). The coast

southwest of Pt. Barrow, the northwest coast of the Seward Peninsula, and the east end of Kotzebue Sound are particularly susceptible (2) to surges.

Most surges occur from mid-June through November when low pressure systems pass (2, 17). Water level increased 3 m above normal when a major storm passed in October 1963 (17). As ice cover drastically reduces these water level fluctuations.

Waves

Data are sparse but show that wave energy is higher than along the Beaufort Sea Coast (11). Sea state generally depends on local winds, which come primarily from the north and northwest (1, 17). Mean wind velocity from these directions is 5-6 m/sec (17). The longer waves and swells approach from the north and northwest, the direction with longest fetch (1, 7). Occasionally waves approach from the southwest (4).

Ice conditions drastically change the wave patterns (17). Wave activity is highest in early autumn decreasing in October. The highest waves observed in the autumn are 7 m. Summer wave heights in the center of the Chukchi Sea are usually < 5 m (17).

Currents

Figures 80-88 illustrate the variability of interpretations and data on the circulation in the Chukchi Sea. Detailed differences can be evaluated in the references cited.

Tidal currents are rotary and very weak (16, 17). They vary from .25-.85 m/sec, depending on the location and tidal stage (1).

Open ocean currents flow northward from the Bering Strait to Pt. Barrow (1, 6). Average rate of flow through the Strait is 1.2×10^6 m^3/sec (17). The north-flowing water is relatively warm, low salinity Bering Sea water (1, 7) that appears to follow the bathymetry to Pt. Barrow (6). It is a semi-permanent flow (9), strong in the summer (17). This flow is the dominant barotropic flow with uniform velocity and direction within the water column. Average velocity is .45 m/sec in the summer, 0.1 m/sec in the winter (7). This flow has many meanders and eddies, and is slowed somewhat by the dominant northeasterly winds (7).

Nearshore current patterns and velocities are very complicated and variable because of coastal configuration, bathymetry, and winds (1, 15, 17). Most of the nearshore currents are wind-driven (9). Water movement from the Bering Strait to Cape Lisburne takes 10-15 days in the summer (7). Other velocities are: Alaska Coastal Water moves north at .5-2 m/sec on the east coast in the Bering Strait (7, 16, 17); on the Siberian side, 0-.5 m/sec (16); .25 m/sec near Diomede Island (7); .5 m/sec near Cape Thompson (7); 15-25 cm/sec for currents parallel to the coast at the surface (0-10 m) in the summer (8); ≈ 40 cm/sec for surface current parallelling the shore near Pt. Hope (8); and, ≈ 30 cm/sec near Icy Cape (8).

Surface currents off Wainwright are weak and variable. They flow 5-30 cm/sec to the northeast. Inshore of the 20 m contour, surface currents are reversed and flow 5-24 cm/sec (9). There is a southwest flow 70 km offshore of Wainwright that is not always plotted. The

anticyclonic eddy on the lee of Ice Cape and Pt. Hope-Cape Lisburne is well-known (9).

The northward flowing coastal current divides near Cape Lisburne. It continues as the North Alaskan Littoral Current along the coast to Icy Cape and Pt. Barrow (16). North of Pt. Barrow it turns west with the Arctic Ocean Gyre (17). During the summer the western Chukchi Sea, a cold (4-6°C) current of low salinity normally flows entering through DeLong Strait (Fig. 80) (17).

Kotzebue Sound currents are mostly tide and wind-induced. Velocities through and within the Sound are very slow, < .1 m/sec (1).

Temperature and Salinity Distributions and Water Masses

Figures 89-104 illustrate the distributions. Seasonal freezing and melting, and fresh water discharge are major influences on sea water characteristics (12, 16). Mixing is strong, especially in the east, due to the shallow sea (6, 7), winds, tides, and currents (12). Summer water is influenced by river input, winds, mixing, and tides. The thermocline in the northern Chukchi Sea is shallow, 10-20 m, due to surface heating in summer (17). Winter conditions are influenced by thermohaline convection as sea water cools and freshwater input decreases (1). Locally, the heavy water sinks (12).

Descriptions of some general features of Chukchi Sea water follow. Water typical of estuaries is found in the coastal lagoons (16). Total freshwater input to the sea averages 2500 m^3/sec (1, 12). Water is relatively warm with low (usually 27^{o}/oo (1, 12)), but variable (28-32^{o}/oo) salinity (16). Cooler water occurs in the northern part along the ice edge and the Siberian coast (1). Low salinity water occurs on the west side from the Bering Strait (12). Chukchi Sea salinities in the Alaskan area vary from about 31^{o}/oo in the summer to 33^{o}/oo in the winter (1). Warmer water at all depths occurs along the Alaskan coast (1). Water temperatures are variable, from 11°C in summer to -1.7°C in the winter (1).

Surface water has lower salinity in summer than in winter due to fresh water input (1, 12). Sea water density increases in the winter due to increasing salt content (because of water freezing and expelling brine) and to heat loss to the atmosphere through leads (12). Northward-

flowing currents are faster in the eastern Chukchi Sea as the ice retreats in the summer (19). A band of fresher water about 30 km wide forms south of the ice edge due to ice melt (12, 19). Meltwater content in the band increases toward the ice (19). Just north of the ice edge the fresh water content of the sea water increases by an amount about equal to the water equivalent of the ice thickness (19).

Surface water flowing into the Arctic Ocean is relatively fresh, but entrains more saline water (12). Salinity in the Arctic ocean is lowest adjacent to the Chukchi Sea because of the major rivers flowing into the sea (12).

Descriptions of more specific patterns in the Chukchi Sea follow. The cold, saline Bering Sea water and warmer, less saline Alaska Coastal Water that passes through the Bering Strait has a temperature of 4-12°C and a salinity of < 30°/oo most of the year (15, 16, 17). Water is warm near shore, up to 10°C, with low salinity, < 31°/oo. The salinity stays the same, both north and south along the Alaskan shore (7). Central and western waters are cold, 1-3°C, and more saline, ≈ 33°/oo (7, 12). Temperatures vary from 0°C near the ice to 10°C off Pt. Hope (7). Coastal waters are relatively warm due to north-flowing littoral currents (16) and runoff from Kotzebue Sound (17). Water temperatures in the winter under the ice vary from -1 to -2°C; they are just above freezing in the summer (16).

During ice-free periods, water at all depths is warm in the eastern sea, 10-15°c, and cold in the western sea, 1.7-2.8°C (1, 12). Salinity in Kotzebue Sound is 20-30°/oo in the summer, 32-34°/oo in winter (1).

Surface water temperatures off the Alaskan coast are below -0.5 to -0.9°C when the ice is near the coast. In the central Sea, surface water is 2-4°C. With minor ice development, surface water temperature near the coast increases to 6°C and in the central part to 4-6°C (17).

Summer water masses in the Chukchi Sea and the Bering Strait are given in Table 8. There are two dominant masses, the Alaskan Coastal Water (ACW) and the Bering Sea Water (BSW) (8). In summer, BSW (1-7°C, 32.2-33‰) dominates the central and western parts of the Sea; ACW (2-10°C, < 32.2‰) dominate the eastern part. ACW grades laterally from relatively cold, saline water in the west, to warm, less saline water near the Alaskan coast (8).

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BERING SEA*

Coastal Environment

Geology

This coast is seismically active and classified in seismic zones 2, 3, and 4 (Fig. 107). In Bristol and Kuskokwim Bays, (Fig. 105) moderate structural damage would be expected during large earthquakes, and sliding along sea bluffs would be common (1). Most earthquakes are shallow along the Aleutian Trench. Depths increase to the north.

Most of Alaska's volcanoes occur in a belt from Mt. Spurr, just west of Anchorage, to Buldir in the western Aleutians (Fig. 106). Most of the volcanoes in the Aleutian Chain have been active since 1760, all are potentially eruptive (1).

Storms cause major changes along this Bering Sea coast. The November 1974 storm eroded up to 45 m of the tundra bluffs near Nome. Elsewhere the storm deposited sediment, forming giant crisps (7).

The northern Norton Sound coast has narrow beaches with steep sea cliffs behind them (16). The shoreline is generally smooth with scattered bays and headlands. Detailed geomorphic features along the coast are shown on the U.S.G.S. topographic maps listed in Table 1.

Coastal Processes

Sediment transport and distribution on the Bering Sea shelf are

* Some figures and tables in the Chukchi and Beaufort Seas sections have information on the Bering Sea, also. Refer to them for additional details.

controlled primarily by normal and storm-generated currents and waves in the winter, and by tidal action (1, 4, 6, 16) in the summer. The mixed tides cause bottom shear which is significant enough during the spring to resuspend sediment (6). Wind-driven mixing and currents also rework bottom sediments on the shelf (16). Ice transport and storm transport of sediment are especially important in Norton Sound (6). Ice covers the northern and most of the eastern Bering Sea in the winter (4).

The coast has scattered erosion. The large shelf provides some protection, and deposition dominates along the Kuskokwim-Yukon delta (1). Thermal erosion occurs locally, especially along shores with fine soils (1). Erosion is slow along the bedrock cliffs of northwest and southeast Bristol Bay but is rapid along the coast adjacent to the Bay lowlands (1). Erosion processes are intensified in Bristol Bay because of its funnel shape. The large tidal range affects a great portion of the shoreline. Erosion rates near Dillingham are 3.7 m/yr along the high bluffs (1). Eolian erosion is important, especially in the Aleutian Chain (1).

Much of the eroded sediment as well as the sediment discharged by the rivers is carried through the Bering Strait by the dominant northern current (4). There is also significant sediment influx into the Norton Sound and the northern Bering Sea, primarily from river runoff. Approximately 90% of the input to the sea comes from the Yukon River (16). A tongue of turbid Yukon River water moves across the mouth of Norton Sound. Yukon River and Alaskan Coastal Water are well-mixed so suspended silt

extends throughout the water column (6).

Tsunamis are often generated in the Aleutian Islands and can be disastrous in this region (1). Upwelling occurs in many areas of the continental shelf, usually at submarine canyon heads. Upwelling is most common between Unalaska and the Pribilof Islands, and north of the Aleutian Island passes (1).

Vegetation

The detailed unit descriptions and the distribution of vegetation from the Bering Strait to Cape Wrangell (including the islands) are available in references 1 and 16. Moist and wet tundra predominate along this coast, especially in the southern part from Norton Sound to Unimak Island and on the islands. High brush occurs along the north shore of Norton Sound. Upland spruce and hardwood forests occur intermittently along the north and east shore of the Sound. Alpine tundra and barren ground, and moist tundra predominate in the Aleutian Islands and on some of the capes of St. Lawrence Island.

Soils

The detailed unit descriptions and the distribution of the soil types along this coast are available in reference 20. The map sheets that cover the coast from the Bering Strait to Cape Wrangell, including the islands, are 11, 12, 15, 18, 22, 25, 27, 28, and 29. The major land resource areas that border this coast are the Norton Sound Highlands, from the Bering Strait to Pt. Romanof; the Western Alaska Coastal Plains and Deltas, from Pt. Romanof to Platinum (Yukon-Kuskokwim Rivers Delta)

and Tuklung to Ilnik (Bristol Bay Coastal Plain); the Kuskokwim Highlands, from Platinum to Tuklung; the Alaska Peninsula and Southwestern Islands, from Ilnik to Cape Wrangell; and the Bering Sea Islands, Pribilof, Nunivak, St. Matthew, and the St. Lawrence Islands; and the mainland, from Niliklugук to Chinigyak Cape.

Land Use

Detailed descriptions and distribution of land use along this coast are given in reference 1. Occasional and intermittent uses predominate. Grazing predominates along the Seward Peninsula from the Bering Strait to Pastol Bay and on St. Lawrence Island. Urban development and small communities and villages are more common along this coast than along the Chukchi and Beaufort Seas. Military installations are scattered. There are numerous state and federal parks, recreation areas, and refuges. There is the Clarence Rhode National Wildlife Refuge (N.W.R.) on the Yukon-Kuskokwim delta; the Nunivak N.W.R. on Nunivak Island; the Cape Newenham N.W.R.; the Izembek N.W.R. on Unimak Island and the tip of the Alaska Peninsula; the Bogoslof N.W.R.; and the Aleutian Islands N.W.R. from Kagamil Island to Cape Wrangell.

Bathymetry

Most of the eastern and northeastern Bering Sea has a shallow smooth continental shelf ("Bering-Chukchi Platform") with a gentle gradient (13, 16) (Fig. 108-113). The shelf is 30-150 m deep and extends to more than 640 km offshore in the northeastern Sea (1, 16, 17).

Average depths are < 100 m (1). Near the Alaskan coast depths are generally 10-50 m, and shoals and banks from river deposits extend many kilometers offshore (1). The Bering Sea Shelf is cut by old stream valleys. Several islands rise abruptly from it (16). The islands have rolling uplands bordered by steep, rocky cliffs.

The shelf narrows along the Aleutian chain and is bordered by an abrupt scarp (4-5° slope) from the shelf edge to the basin floor (Fig. 113)(1, 17). Passes between the Aleutian Islands vary from 45-455 m deep (1). The shelf is covered with sand, silt near the continental slope, and clayey diatomaceous oozes in the basins (17).

The continental slope has many submarine canyons (Fig. 113). The ocean basin, up to 3640 m deep, is a smooth almost featureless floor (1). The Bering Canyon in the southeastern part has a .5° slope (17).

Norton Sound floor has an average depth of 20 m, a gentle westward slope, and rises abruptly to form St. Lawrence Island (16). The shelf is flat from St. Lawrence Island to the Bering Strait.

Bering Strait has an irregular bottom 60 m deep on the east, 52 m on the west, and abruptly rises to form Little and Big Diomede Islands and Fairway Rock. The bathymetry here was probably formed from scouring by strong northerly currents, ice, and ancient river action (16). The narrow depression west of Cape Prince of Wales widens to the north; along its margins are many small surface irregularities with up to 7 m of relief (16).

Physical Oceanography

Tides

The tidal wave enters the Bering Sea from the Pacific Ocean and influences the tidal types up to the Bering Strait (Figs. 114-118) (1, 16). Tides are diurnal along the central and western Aleutian Islands. Mean semi-monthly ranges are 0.5-1.5 m (17). Along the Alaskan coast from the Alaska Peninsula to the Bering Strait, tides are mixed with a mean range of 1-1.5 m (16). Bristol Bay has a 5 m tidal range (1, 17) and two tides per day (18). Tides are diurnal north from Dutch Harbor (Fig. 117)(18). Tides are mixed southeast of St. Lawrence Island, diurnal in Norton Sound, and minor and semi-diurnal in the Bering Strait (19).

Meteorological tides produce some of the largest water level changes (16). Strong westerly winds may raise sea level several meters along the coast where the shelf is shallow (5, 18). Low atmospheric pressure in summer can raise sea level more than 3 m in 6 days. This effect is reduced in the winter (16).

Storm Surges and Water Levels

Surges are rare along the north coast of the Alaska Peninsula because of the limited fetch. North from Bristol Bay, surges occur only when sea ice is absent, from the end of April to mid-December in the south, from mid-June to mid-November in the north (2)(Fig. 119).

The large surges usually occur along the north shore of Norton

Sound (16). A storm in 1946 produced a 3 m surge which flooded Nome and caused increased coastal erosion (16). During a November 1974 storm, the water level rose an estimated 7.6 m (2) at Nome. This southerly storm especially attacked the south and southwest facing coasts, flooding Nome, Unalakleet, Shishmaref, Deering, and Kotzebue (16).

Waves

Rough seas are common in the open ocean (1) and high waves are frequently caused by local high winds (Figs. 120 to 146). Waves in the northern sea are dominated by locally generated sea. There are frequent summer storms in the northern Bering Sea and Norton Sound (16). Swells from the south Bering Sea are reduced over the shelf. Unless there are strong onshore winds, resulting nearshore waves are low (7).

Bristol Bay waves are usually generated by local winds. The Aleutians have significant wind waves. Usually summer winds elsewhere are variable and intermittent, and so do not generate large waves (1).

Winter winds frequently form 1.5 m waves on the ice-free portion of the Bering Sea (16). During ice-free periods, the waves are lower because of lower winds (16).

Currents

Tidal currents are locally important, dominating flow in some places (5). They set northward and southward along the Bering Sea coast (3). However, the tidal flow is usually masked by wind currents (3).

In the Aleutian Island passes, flow is chiefly tidal with strong

ebb and flood components (1, 3, 17). Velocity varies from 150-400 cm/s (3, 17). The complex bathymetry complicates flow patterns, making flow through these passes is highly variable and unpredictable. North and south flows can occur simultaneously in the same pass (9). A flow of 6 m/s was recorded at Akun Strait (1). Flow into the Bering Sea is primarily from the Alaska Current through the passes (1, 9).

Tidal currents occur near the off-lying islands with velocities of .3-.5 m/s (3). The nearshore currents at many locations on the shelf are primarily tidal currents (1). Tidal currents of .4-2 m/s were observed parallel to the coast near Nome (16). Tidal currents in the northern Bering Sea and Norton Sound are complex (19). Current directions change from east to west with each flood and ebb in Norton Sound (16). Flow through the Bering Strait is three to four times greater in August and September than in February and March because of differences in winter and summer tides (17). Bristol Bay has tidal currents of 3 m/s because of its large tidal range (1, 18).

The primary driving mechanisms for the circulation and the water structure in the Bering Sea are wind stress and other meterological conditons (11, 13). Major current changes occur in a short time due to winds (16). Current prediction is difficult because of the rapidly changing weather (3).

A general counterclockwise circulation with small eddies prevails in the Bering Sea (Figs. 146-159) (10). Currents over the basin are a few cm/s, near the continental slope they are 10-15 cm/s (10). During

the open water season there is a generally northern drift along the coast through the Bering Strait along the east side of the Bering Sea near shore and into the Arctic Ocean (3). This flow provides about 20% of the flow into the Arctic Ocean (1). On the east side of the Strait, a 2 m/s flow was measured (1). Currents through the Strait are three to four times faster in August and September than they are in the winter. South of the Bering Strait part of the north-flowing current turns west and forms the cold, south-flowing Siberia Current (16).

Mean annual water transport through the Strait is about 1.5×10^6 m^3/s. Winter flow is about 66 to 75% of the summer flow (16). The net flow through the Strait in the winter of 1976-77 was north (19). Mean current was 10 cm/s, southwest of St. Lawrence Island, 5 cm/s. Reversals from northern flow to southern flow and vice versa with velocities of up to 50 cm/s were superimposed on the mean northerly flow (19).

The north-flowing water is warmed by the Yukon River water before going through the Strait. The water branches at 175° W near the coast. The branches flow to the east and to the west of St. Matthew Island, then turn east of St. Lawrence Island near the Strait. Between the branches is a large semi-permanent gyre (16).

Outer Bristol Bay has a simple counterclockwise gyre from April to early November which is driven by wind, tides, and estuarine affects (1). This gyre can be inferred from the patterns of sediment suspended on the surface of the Bay. Other data also indicate its existence.

Winter circulation is similar to summer circulation although the

ice pack deflects more of the north-flowing current westward into the south-flowing current off the Siberian coast. This current joins the Oyashio Current in the southwestern Bering Sea and the northwestern Pacific (16). The remainder of the northerly flow proceeds north under the ice pack. Winter currents can be locally faster than summer currents (16).

Upwelling is common over large portions of the shelf edge and some of the eastern Aleutian passes (5).

Surface currents in the northern Bering Sea are complex but generally flow north (16). Average velocity is 7-75 cm/s; mixing is minimal between the Alaskan Coastal Water and the Bering Sea Water (14). Major eddies form between the northerly current and the cold southerly current on the Siberian side. Northerly currents of .5 m/s accellerate as they approach the Strait (16).

Circulation in the Norton Sound is affected by wind, freshwater input, convection, and influx from the Bering Sea (16). Wind-induced mixing may extend to the bottom, so the Sound is frequently well-mixed (16). Suspended sediment patterns result from the inflow of the Bering Sea.

Temperature and Salinity Distributions and Water Masses

Figures 160-192 show the temperature and salinity distributions in the Bering Sea. Generally, in the deeper, western part of the Sea, low salinity shelf water disperses in the surface layer. Upwelling associated with circulation eddies reconstructs a stratified vertical

pattern over the deep basin; basin water flows out as the East Kamchatka Current (10). The continental shelf to the east has various vertical temperature and salinity structures (10).

The shallow eastern Bering Sea is characterized by pronounced seasonal stratification. Over the continental shelf freshwater diluting the surface layer, warm, saline water intruding near the bottom, and winter cooling causing strong vertical mixing create dichothermal water (10). A strong thermocline and halocline develop as deep as 20 m in the summer (14). Severe summer storms alter the surface currents and surface water, and cause good mixing in the normally stratified water (1, 14). A homogeneous water mass forms, moves westward, and is replaced by water from the Bering Sea shelf and the Yukon River (14). Local mixing is also increased by amplified tides in the southeastern Bering Sea.

Salinity distributions are influenced by currents, bathymetry, and coastal topography. Generally, salinity increases from east to west due to freshwater from Alaskan rivers. Summer patterns are variable but salinity is usually between 13-19^{o}/oo in eastern Norton Sound, and between 32-33^{o}/oo in northern Bering Sea (16). Winter patterns also vary, between 31-34^{o}/oo (16). In western and eastern Norton Sound, salinity generally increases with depth, but in the eastern Sound deep saline Bering Sea water and fresh surface water can get well-mixed in the summer (16).

The number of water masses in the Bering Sea vary according to various investigators. Reference 10 lists three: Western Subarctic Water, Bering Sea Water, and Alaska Stream Water. Reference 14 describes

three different masses: Alaskan Coastal Water (ACW), North St. Lawrence Water, and Basin Water. ACW (8-13°C, < 32^{o}/oo) is dominant along the coast. Three water masses are defined in Reference 17. Over the continental shelf, water is cooled in winter, diluted in the spring, warmed in the summer, with temperature variations from -1.6° to 10°C, and salinity variations from $22-32.8^{o}$/oo. The surface layer over the deep basin comes from south of the Aleutian Islands and is modified by heating and cooling. Temperatures vary from 1-9°C, salinity from 32.9-33.2^{o}/oo. Water below 200 m in the basins comes from depths of greater than 600 m in the Pacific Ocean; its temperature varies from 1.51 $\pm$0.2°C, and its salinity from 34.68 $\pm$.02^{o}/oo.

Several water types are defined in reference 1. Bering Sea water has two types. Continental shelf water is cooled by convection under the ice in the winter by runoff and diluted in the spring (-1.6°C). Its temperature is 11°C in mid-summer. Shelf water salinity and temperature are controlled by runoff from April to November; its density and salinity are changed by ice melt in Bristol Bay. Salinity ranges from $22-32.8^{o}$/oo. Deep basin water has original salinity like that of Aleutian Island water. Its temperatures vary from 1.1° to 8.9°C, its salinities from $32.9-33.2^{o}$/oo.

Bristol Bay has four water types. North Pacific water has a salinity of $\approx 32.7^{o}$/oo and a temperature between 5°-10°C, with a mean of 7.2°C. Slope water is a mixture of other types with an average surface temperature of 8.6°C, a temperature range of 5° to 10.6°C, and an average salinity

of 32.75^{o}/oo. Outer Bay water has a temperature range from 1.7°-12.2°C, an average temperature of 7.8°C, and a mean salinity of 31.4^{o}/oo. Coastal and inner Bay water has an average surface temperature of 11.2°C with a minimum of 1.4°C; its salinity averages 28.9^{o}/oo with a range of 12.4-31.2^{o}/oo.

Aleutian Chain water has a winter temperature of 0°-1.9°C and a summer temperature of 1.1°-2.8°C.

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Table 1. U.S. Geological Survey 1:250,000 topographic maps covering the Alaskan coast from the U.S.-Canadian border to Cape Wrangell.

1. Demarcation Pt.
2. Barter Isl.
3. Flaxman Isl.
4. Mt. Michelson
5. Beechey Pt.
6. Harrison Bay
7. Teshekpuk
8. Barrow
9. Meade River
10. Wainwright
11. Pt. Lay
12. Delong Mts.
13. Pt. Hope
14. Noatak
15. Baird Mts.
16. Selawik
17. Kotzebue
18. Shishmaref
19. Teller
20. Nome
21. Solomon
22. Norton Bay
23. Unalakleet
24. St. Michael
25. Kwiguk
26. Black
27. Hooper Bay
28. Marshall
29. Baird Inlet
30. Nunivak Isl.
31. Cape Mendenhall
32. Kuskokwim Bay
33. Goodnews
34. Hagemeister Isl.
35. Nushagak Bay
36. Naknek
37. Ugashik
38. Bristol Bay
39. Chignik
40. Port Moller
41. Cold Bay
42. False Pass
43. Unimak
44. Unalaska
45. Umnak
46. Samalga Isl.
47. Amukta
48. Seguam
49. Atka
50. Adak
51. Gareloi Isl.
52. Rat Isls.
53. Kiska
54. Attu
55. Pribilof Isls.
56. St. Matthew
57. St. Lawrence

Table 2. Distinctions between outer and inner-bar rhythmic topographies (from Beaufort Sea ref. 25).

Outer-Bar Rhythm (300–3,000 m)*	Inner-Bar Rhythm (order of 10^2 m)
Shape:	
Predominantly symmetrical†	Skewed shape frequent†
Continuous series†	Discontinuous series more frequent
Correlation with shoreline rhythm:	
Often out of phase between bar and shoreline rhythms	Usually in phase†
Shoreline rhythm may be smooth	Shoreline rhythms always present†
Bar points not necessarily contiguous to shore	Oblique shoals anchored at horns†
(ridge and swale topography preserved on shoreline rhythms)	
(landward extent of shoreline rhythms difficult to delimit on low barrier islands)	
Modification and movement:	
Bar rhythm relatively stable after formation†	Both bar and shore rhythms ephemeral
Bar and shoreline rhythms may migrate independently†	No sustained longshore migration
Little movement normal to shore†	Active shoreward migration and climb on shore under swell activities
Correlation with nearshore currents:	
Tends to skew downdrift under longshore currents†	Oblique bar develops a gentle upstream slope and steep lee slope†
Generates circulation of moderate speeds†	Generates strong circulations and meandering currents with rips

NOTE.—Characteristics in parentheses are unique to arctic bars and were inserted by the writer (after Sonu 1973).
* Wavelength at Pingok Island 5,000–6,000 m.
† Agreement with ground and aerial observations of bar form 3.

Table 3. Sea height (ft) versus direction from 1 July to 20 November (from Beaufort Sea ref. 21).

SEA DIRECTION \ SEA HEIGHT	< 3	3	5	6.5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	39	12											51	2.1
NNE	38	17			2								57	2.4
NE	108	8	2				1						119	4.9
ENE	141	28	5										174	7.2
E	176	29	2		2							2	211	8.7
ESE	53	5											58	2.4
SE	15	1		1									17	0.7
SSE	18	2											20	0.8
S	4	1											5	0.2
SSW	10	2											12	0.5
SW	13	5											18	0.7
WSW	31	4	2										37	1.5
W	71	16	5	2	2								96	4.0
WNW	35	19	25	5	1				1				86	3.7
NW	28	10	3	6									47	2.0
NNW	29	8											37	1.5
CALM	1370												1370	56.7
C -15														
C +15														
TOTAL	2178	168	44	14	7		1		1			2	2415	
%	90.2	7.0	1.8	0.6	0.3		0.0		0.0			0.1		100.0 / 100.0

MARINE AREA 6

(from between Wainwright and Barrow to the east side of Harrison Bay)

Table 4. Sea height (ft) versus direction from 11 July to 31 October (from Beaufort Sea ref. 21).

SEA DIRECTION	<3	3	5	6.5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	2												2	0.2
NNE	4	4											8	1.0
NE	8	1											9	1.1
ENE	32	2	2										36	4.4
E	68	23	2										94	11.5
ESE	25	9											34	4.2
SE	4	3											7	0.9
SSE	8	6											14	1.7
S	5	1											6	0.7
SSW	3			2									5	0.6
SW	7												7	0.9
WSW	2	3											5	0.6
W	34	7	4										45	5.5
WNW	36	10	3	4									63	7.7
NW	37	6		3	1		1						48	5.9
NNW	5			2									7	0.9
CALM	428												428	52.3
C -15														
C +15														
TOTAL	706	77	12	21	1		1						818	
%	86.3	9.4	1.5	2.6	0.1		0.1							1001 / 1000

MARINE AREA 4

(from the east side of Harrison Bay to Camden Bay)

SEA HEIGHT

SEA DIRECTION	<3	3	5	6.5	8	9.5	11	13	14	16	17-29	30+	TOTAL	%
N	4	1											5	0.5
NNE	4												4	0.4
NE	24	8	2										34	3.2
ENE	48	7	3										68	6.4
E	57	45	9										111	10.4
ESE	16	3											19	1.8
SE	4	8	2						1				15	1.4
SSE	1												1	0.1
S	3								3				6	0.6
SSW	2												2	0.2
SW	8	1											9	0.8
WSW	6												6	0.6
W	33	6	2	2									43	4.0
WNW	21	7											28	2.6
NW	14	5											19	1.8
NNW	2												2	0.2
CALM	696												696	65.2
C -15														
C +15														
TOTAL	953	91	18	2					4				1068	
%	89.2	8.5	1.7	0.2					0.4					100.2 / 1000

MARINE AREA 5

(from Camden Bay to across the U.S.-Canadian border)

Table 5. Wind speed and direction versus sea height from 1 July to 20 November (from Beaufort Sea ref. 21).

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	NNE & NE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	11	34	34	46	11	2		178	8	87	107	92	58	2		346
3			3	8	4			15		2	2	11	14	4		33
5				1	2			3				2				2
6.5						2		2								
8													2			2
9.5																
11												1				1
13																
14																
16																
17.5																
30+																
TOTAL	11	34	37	50	15	6		198	8	89	109	106	64	6		384
%	0.4	1.3	2.4	2.1	0.6	0.2		8.2	0.3	3.7	4.5	4.4	2.7	0.2		15.9

SEA HEIGHT (FEET)	ENE & E 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	ESE & SE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	16	104	181	207	111	9		628	16	62	82	40	11			219
3			3	13	20	7		43	1		5	5	6	1		18
5			1	1	3	2		7								
6.5						1		1								
8			2					2								
9.5																
11																
13																
14																
16																
17.5																
30+												2				2
TOTAL	16	104	187	221	134	19		681	17	62	87	55	17	1		239
%	0.7	4.3	7.7	9.1	5.5	0.8		28.1	0.7	2.6	3.6	2.3	0.7	0.0		9.9

SEA HEIGHT (FEET)	SSE & S 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	SSW & SW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	10	51	46	27	6			140	6	27	46	58	6			143
3			1	5	1			7			1	4				5
5						1		1					2			2
6.5																
8																
9.5																
11																
13																
14																
16																
17.5																
30+																
TOTAL	10	51	47	32	7	1		148	6	27	47	62	8			150
%	0.4	2.1	1.9	1.3	0.3	0.0		6.1	0.2	1.1	1.9	2.6	0.3			6.2

SEA HEIGHT (FEET)	WSW & W 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	WNW & NW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	TOTAL	%
<3	83	56	85	89	19			332	20	54	64	48	9			197	2183	90.2
3	1	1	2	12	9			25				12	9	1		22	168	6.9
5					5	3		8				1	17	4		22	45	1.9
6.5													6	5		11	14	0.6
8					2			2						1		1	7	0.3
9.5																		
11																	1	0.0
13																		
14			1					1									1	0.0
16																		
17.5																		
30+																	2	0.1
TOTAL	84	57	88	101	35	3		368	20	54	66	61	41	11		253	2421	
%	3.5	2.4	3.6	4.2	1.4	0.1		15.2	0.8	2.2	2.7	2.5	1.7	1.5		10.5		100 / 100.0

MARINE AREA 6

Table 6. Wind speed and direction versus sea height from 11 July to 31 October (from Beaufort Sea ref. 21).

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	NNE & NE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3		18	9	13	2			42		16	13	17				46
3		2	2					4		1	2	1				4
5																
6.5				1				1								
8																
9.5																
11			1					1								
13																
14																
16																
17.5																
30+																
TOTAL		20	12	14	2			48		17	15	18				50
%		2.4	1.5	1.7	0.2			5.8		2.1	1.8	2.2				6.1

SEA HEIGHT (FEET)	ENE & E 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	ESE & SE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	5	41	93	87	14			240	1	16	26	33	5	1	1	83
3			2	19	10	2		33			2	2	3			7
5				1	2			3					1			1
6.5																
8																
9.5																
11																
13																
14																
16																
17.5																
30+																
TOTAL	5	41	95	107	26	2		276	1	16	28	35	9	1	1	91
%	0.6	5.0	11.6	13.3	3.2	0.2		33.6	0.1	1.9	3.4	4.3	1.1	0.1	0.1	11.1

SEA HEIGHT (FEET)	SSE & S 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	SSW & SW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	2	11	10	6				29	1	8	11	4	1			25
3				2	2			4								
5				1				1								
6.5													2			2
8																
9.5																
11																
13																
14																
16																
17.5																
30+																
TOTAL	2	11	10	9	2			34	1	8	11	4	3			27
%	0.2	1.3	1.2	1.1	0.2			4.1	0.1	1.0	1.3	0.5	0.4			3.3

SEA HEIGHT (FEET)	WSW & W 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	WNW & NW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	TOTAL	%
<3	52	25	18	20	5		1	121	2	33	40	37	11			123	709	84.4
3				3	3			6		1	4	6	8			19	77	9.4
5				2				2				4	1			5	12	1.5
6.5				2	2			4				2	10	2		14	21	2.6
8												1				1	1	0.1
9.5																		
11																	1	0.1
13																		
14																		
16																		
17.5																		
30+																		
TOTAL	52	25	18	27	10		1	133	2	34	44	50	30	2		162	821	
%	6.3	3.0	2.2	3.3	1.2		0.1	16.2	0.2	4.1	5.4	6.1	3.7	0.2		19.7		99.9 / 100.1

MARINE AREA 4

Table 7. Wind speed and direction versus sea height from 11 July to 31 October (from Beaufort Sea ref. 21).

WIND SPEED (KNOTS) AND DIRECTION

SEA HEIGHT (FEET)	NNW & N 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	NNE & NE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	2	24	6	5	3			40	11	45	40	29	3			128
3											2	12				14
5											1		2			3
6.5													1			1
8																
9.5																
11																
13																
14																
16																
17.5																
30+																
TOTAL	2	24	6	5	3			40	11	45	43	41	6			146
%	0.2	2.2	0.6	0.5	0.3			3.7	1.0	4.2	4.0	3.8	0.6			13.6

SEA HEIGHT (FEET)	ENE & E 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	ESE & SE 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	12	64	83	96	21	1		277	6	19	32	23	3			83
3		2	2	30	10	1	1	46				8	3			11
5				4	3	2		9				2	2			4
6.5																
8																
9.5																
11																
13																
14	2	1						3					1			1
16																
17.5																
30+																
TOTAL	14	67	85	130	34	4	1	335	6	19	32	33	9			99
%	1.3	6.3	7.9	12.1	3.2	0.4	0.1	31.3	0.6	1.8	3.0	3.1	0.8			9.2

SEA HEIGHT (FEET)	SSE & S 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	SSW & SW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL
<3	2	20	8	3				33	6	15	12	7	8			48
3				1				1					1			1
5																
6.5																
8																
9.5																
11																
13																
14																
16																
17.5																
30+																
TOTAL	2	20	8	4				34	6	15	12	7	9			49
%	0.2	1.9	0.7	0.4				3.2	0.6	1.4	1.1	0.7	0.8			4.6

SEA HEIGHT (FEET)	WSW & W 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	WNW & NW 0-2	3-7	8-12	13-20	21-30	31-40	40+	TOTAL	TOTAL	%
<3	79	41	50	35	16			221	5	36	34	43	6	2		126	956	89.3
3			1	4	1			6		3	6	1	1	1		12	91	8.5
5				1	1			2									18	1.7
6.5				1				1									2	0.2
8																		
9.5																		
11																		
13																		
14																		
16																	4	0.4
17.5																		
30+																		
TOTAL	79	41	51	41	18			230	5	39	40	44	7	3		138	1071	
%	7.4	3.8	4.8	3.8	1.7			21.5	0.5	3.6	3.7	4.1	0.7	0.3		12.9		100.0 / 100.1

MARINE AREA 5

Table 8. A description of water masses found in the Bering Strait and Chukchi Sea during the summer of 1949 (Saur et. al. 1954) and the summer of 1968 (Kinney et. al. 1970) (from Chukchi Sea ref. 12).

Eastern Bering Sea and Chukchi Sea, Summer 1949	
Deep Shelf Water	Uniform cold, high-salinity water derived from winter conditions and lying along the bottom in the deeper regions of the Bering and Chukchi Sea shelves, but no present in the Bering Strait in late summer.
Modified Shelf Water	Deep shelf water which has retained its high salinity, but since it is near the surface has been warmed several degrees.
Alaskan Coastal Water	Warm water along the coast with greatly varying salinities caused by fresh water drainage from the west coast of Alaska.
Intermediate Water	A wedge of water lying between, and probably formed by mixing between, modified shelf water and Alaskan coastal water.
Siberian Coastal Water	A counter part to the Alaskan coastal water but lower in temperature, resulting from drainage on the north coast of Siberia.
Ice Melt	Low salinity water at the surface in the immediate vicinity of, and in temperature equilibrium with, the melting ice.
Modified Ice Melt	Surface water fringing the ice melt and having similar salinities but modified by heating.
Bering Strait, Summer 1968	
Central Deep Water	Deep water in the center of the strait and surface water on the western side with high nutrients, low organics, high salinity, and low temperature.
Central Surface Water	Surface water in the central strait with partially depleted nutrients, high organics, and varying temperature and salinity.
Eastern Deep Water	Deep water in the eastern strait with low nutrients and high organics.
Eastern Surface Water	Surface water in the eastern strait with low nutrients, low organics, low salinity, and high temperature.

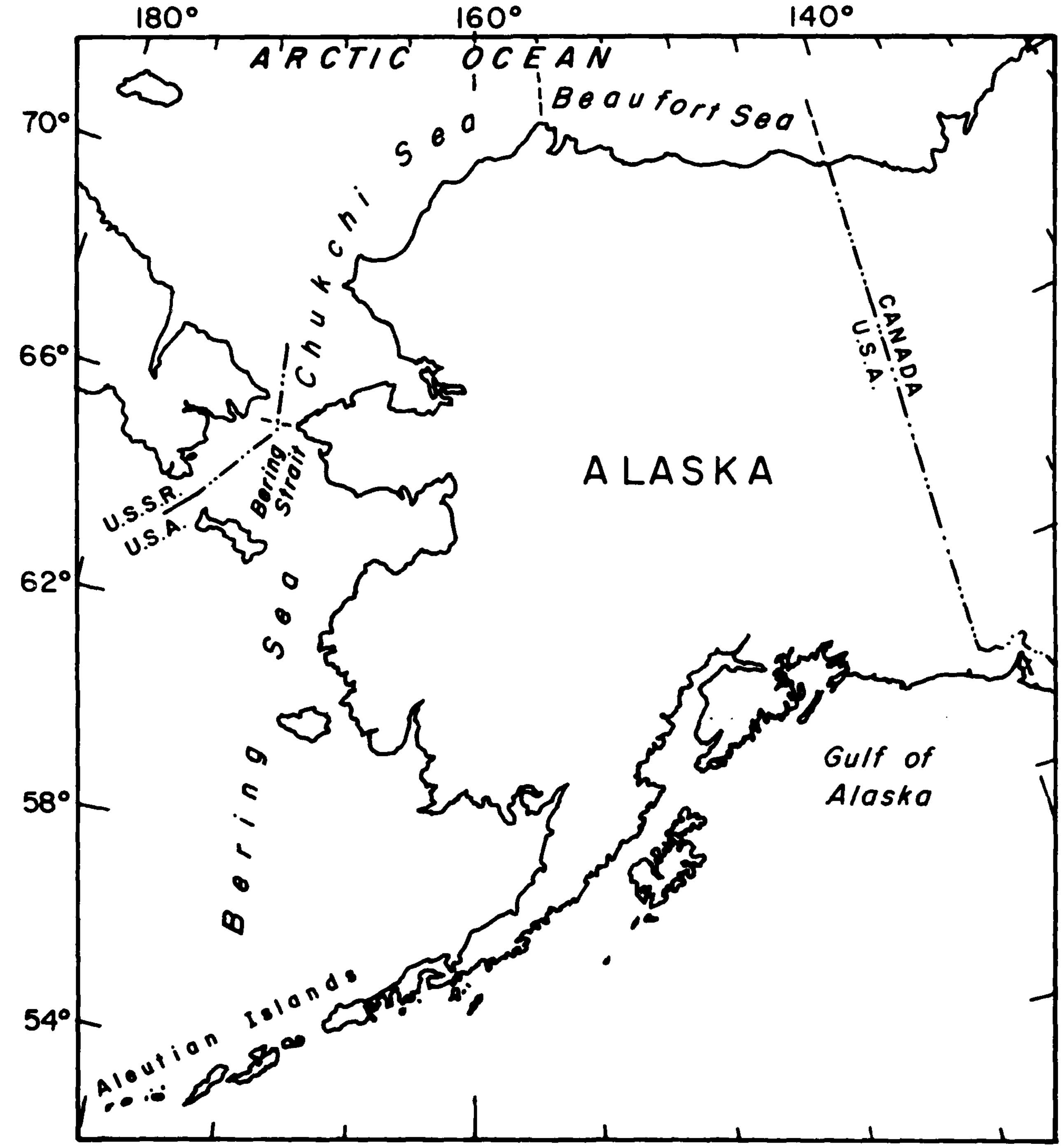


Figure 1. General location map of coastal areas.

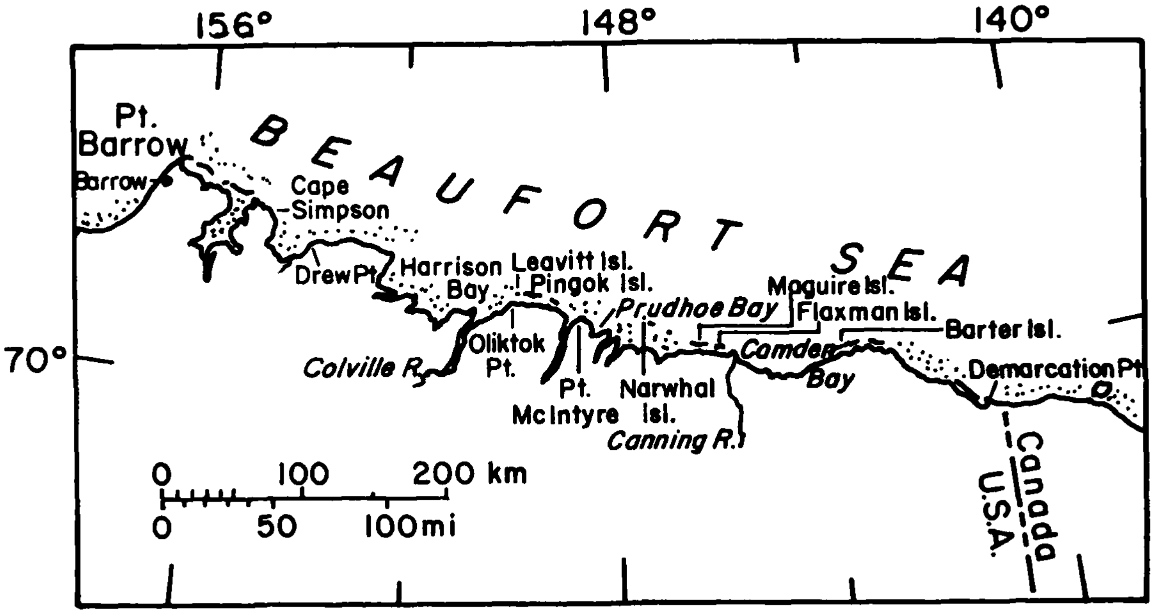


Figure 2. Beaufort Sea coast from the U.S.-Canadian border.

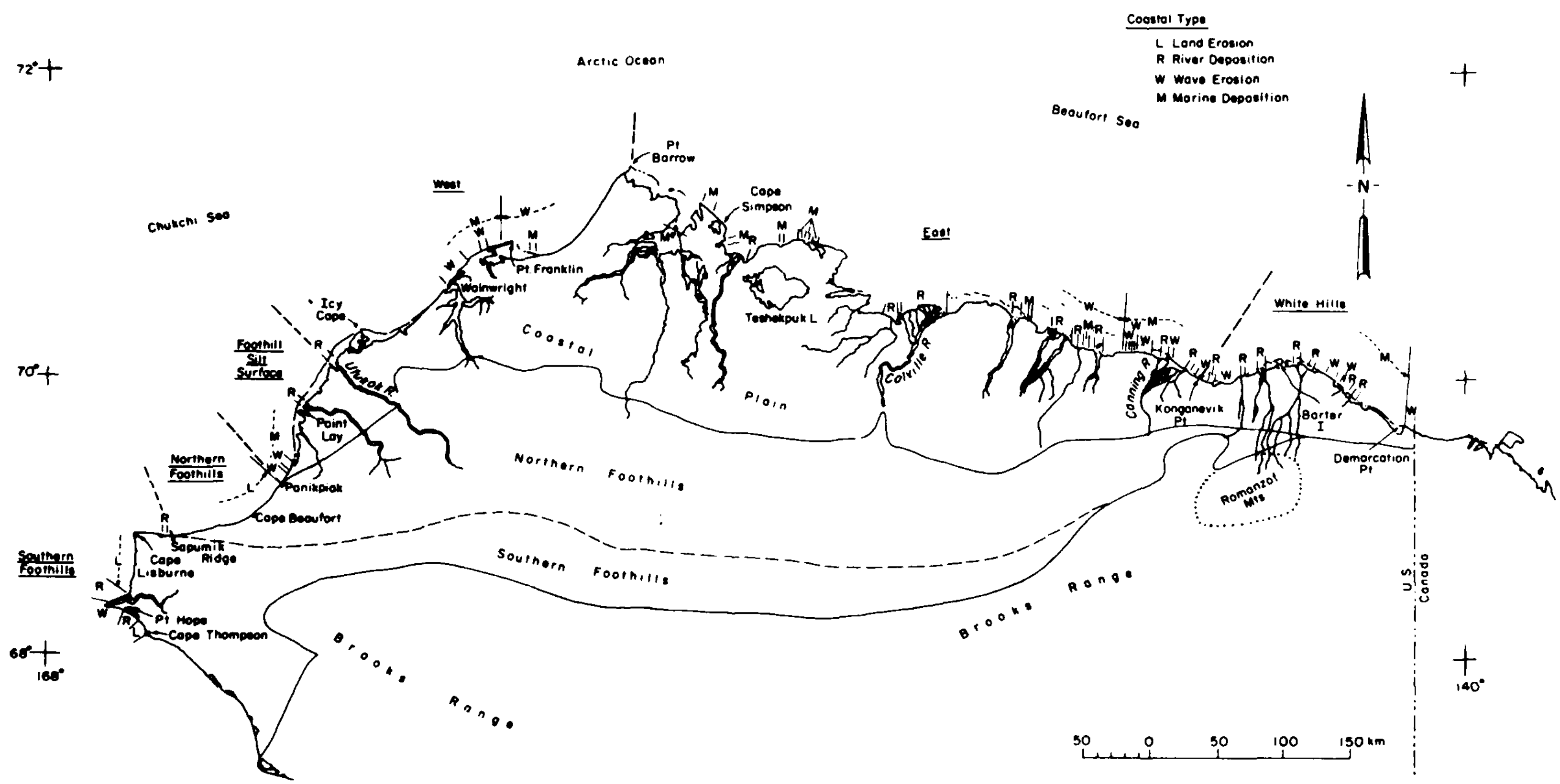


Figure 3. Distribution of geographic regimes and coastal types in Northern Alaska (from Beaufort Sea ref. 8).

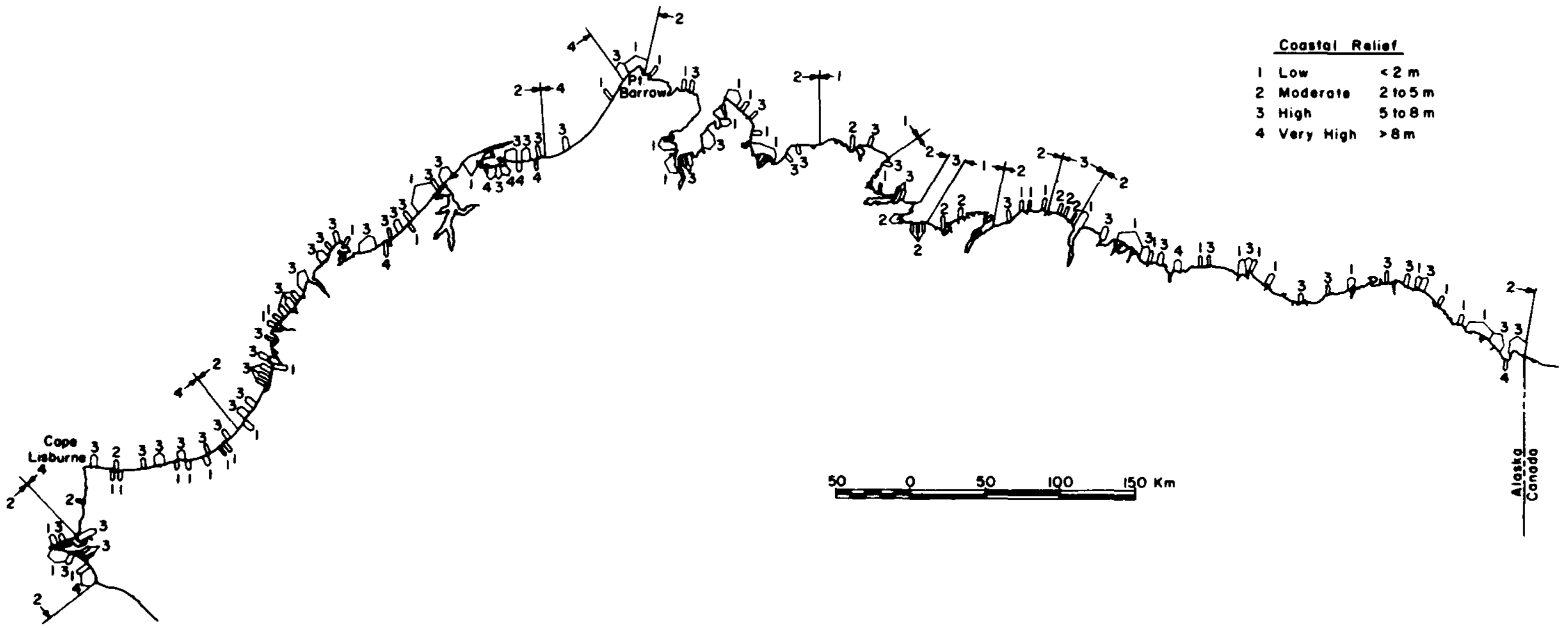


Figure 4. Distribution of coastal relief class (from Beaufort Sea ref. 8).

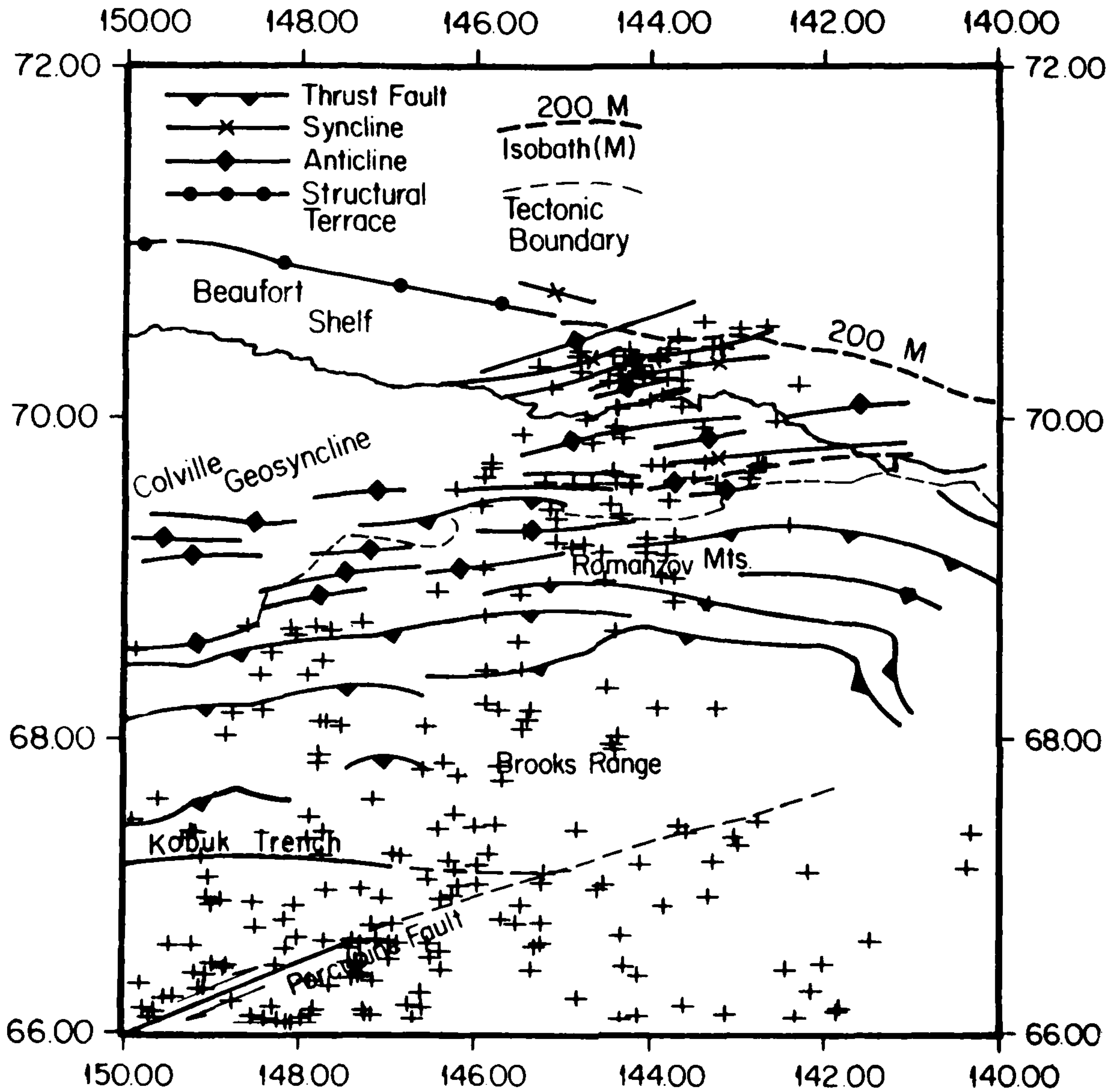


Figure 5. Epicenters (+) of earthquakes located during 1976 and 1977 by the local seismographic network having rms of travel-time residuals $\lesssim$ 1.5 sec plotted on an overlay of the structural traces in northeast Alaska. The epicenters shown north of 70°N. latitude are from Canadian catalog. (Biswas, 1977) (from Beaufort Sea ref 17).

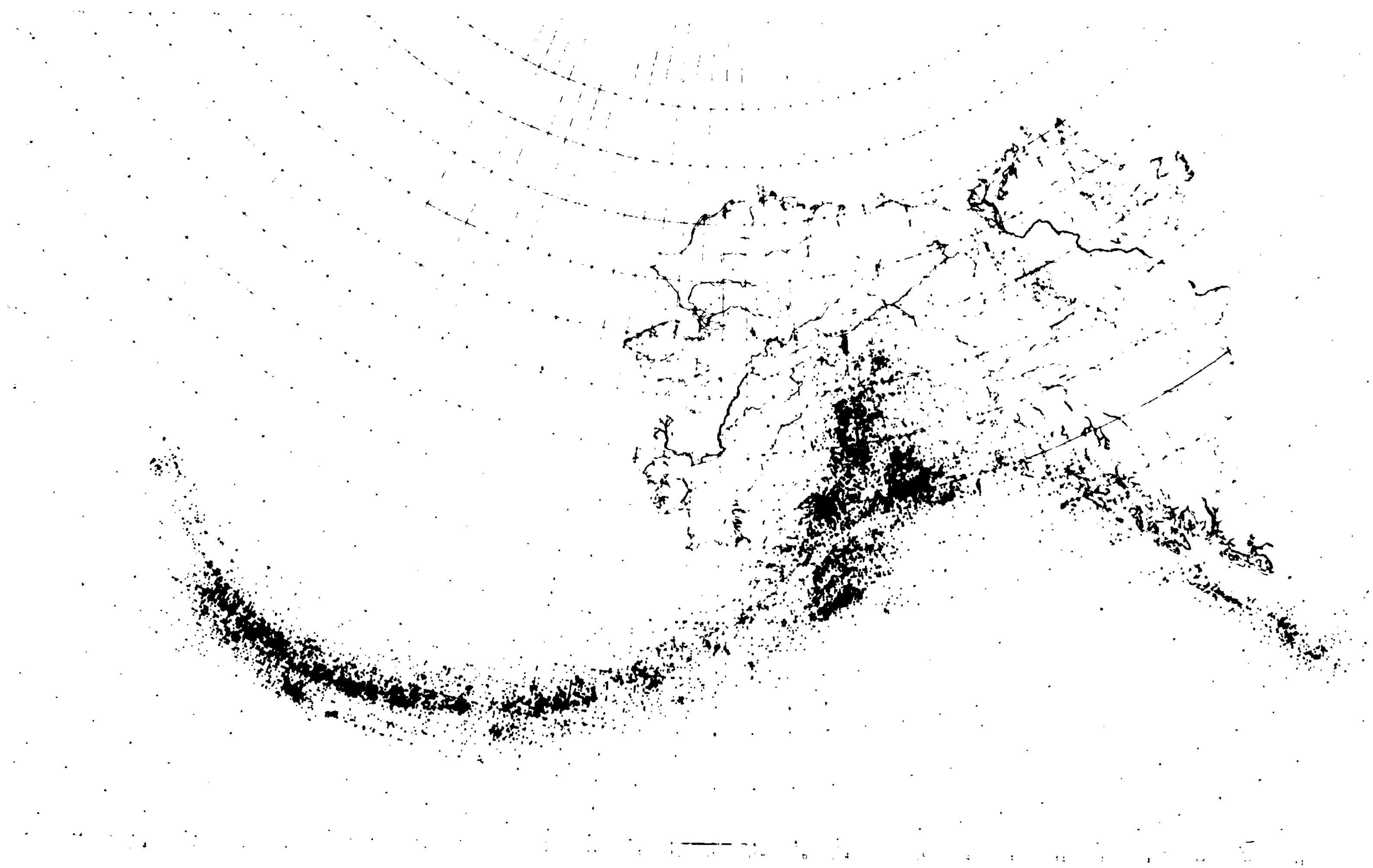


Figure 6. Earthquakes in and near Alaska through 1974 (from Beaufort Sea ref. 8).

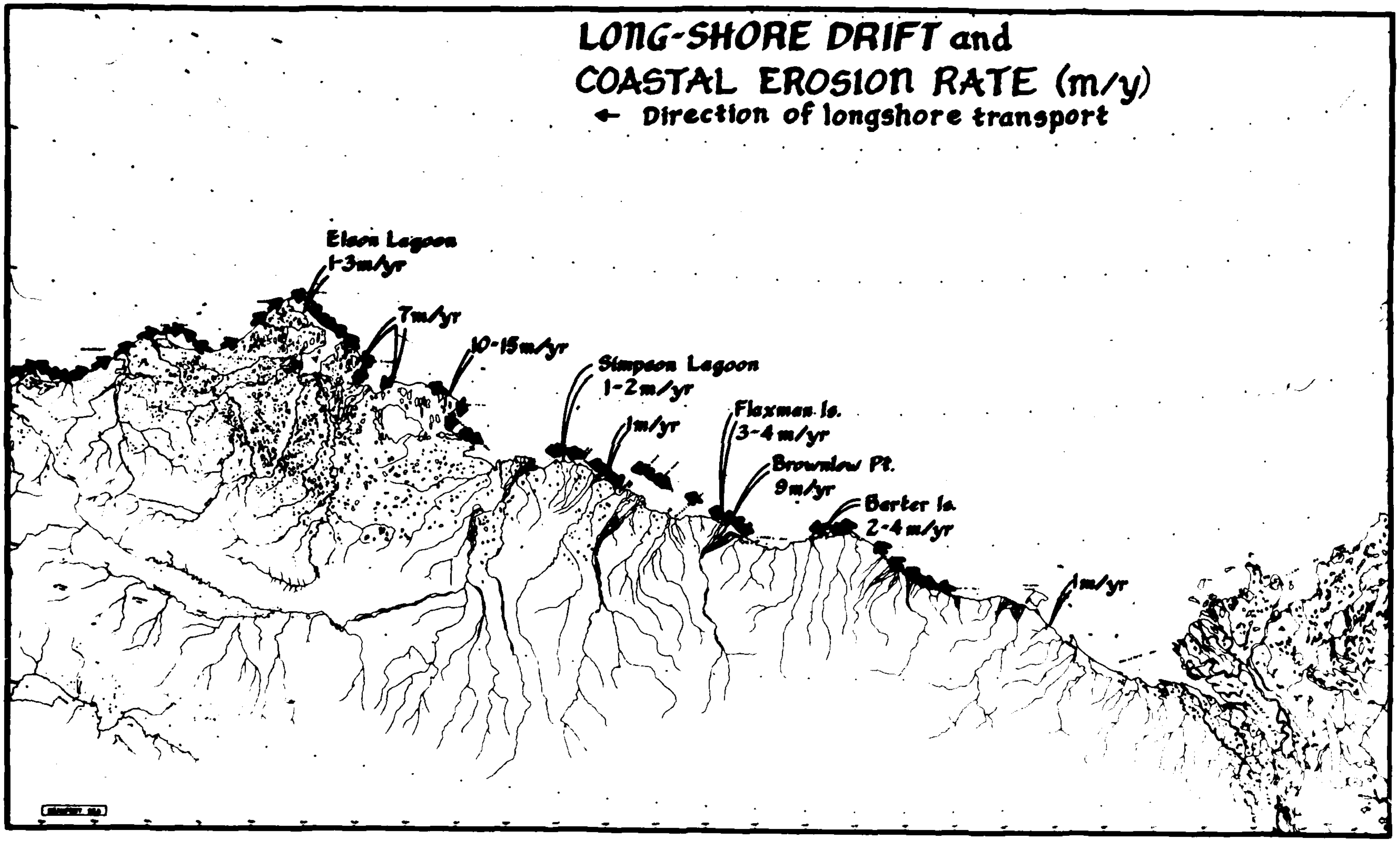


Figure 7. Long-shore drift and coastal erosion rate (Hopkins et. al., 1977) (from Beaufort Sea ref. 17).

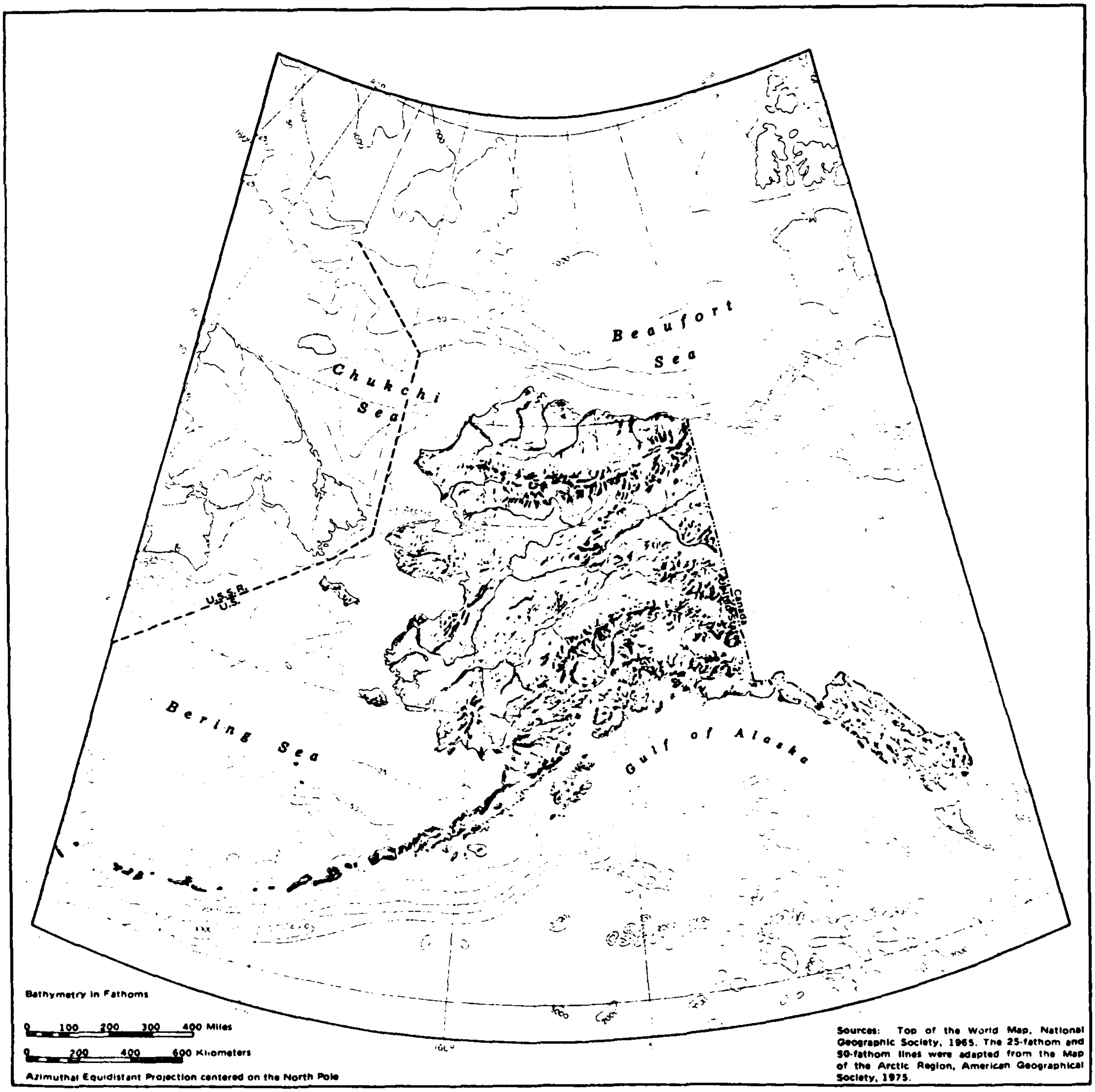


Figure 8. Bathymetry and topography (from Bering Sea ref. 2).

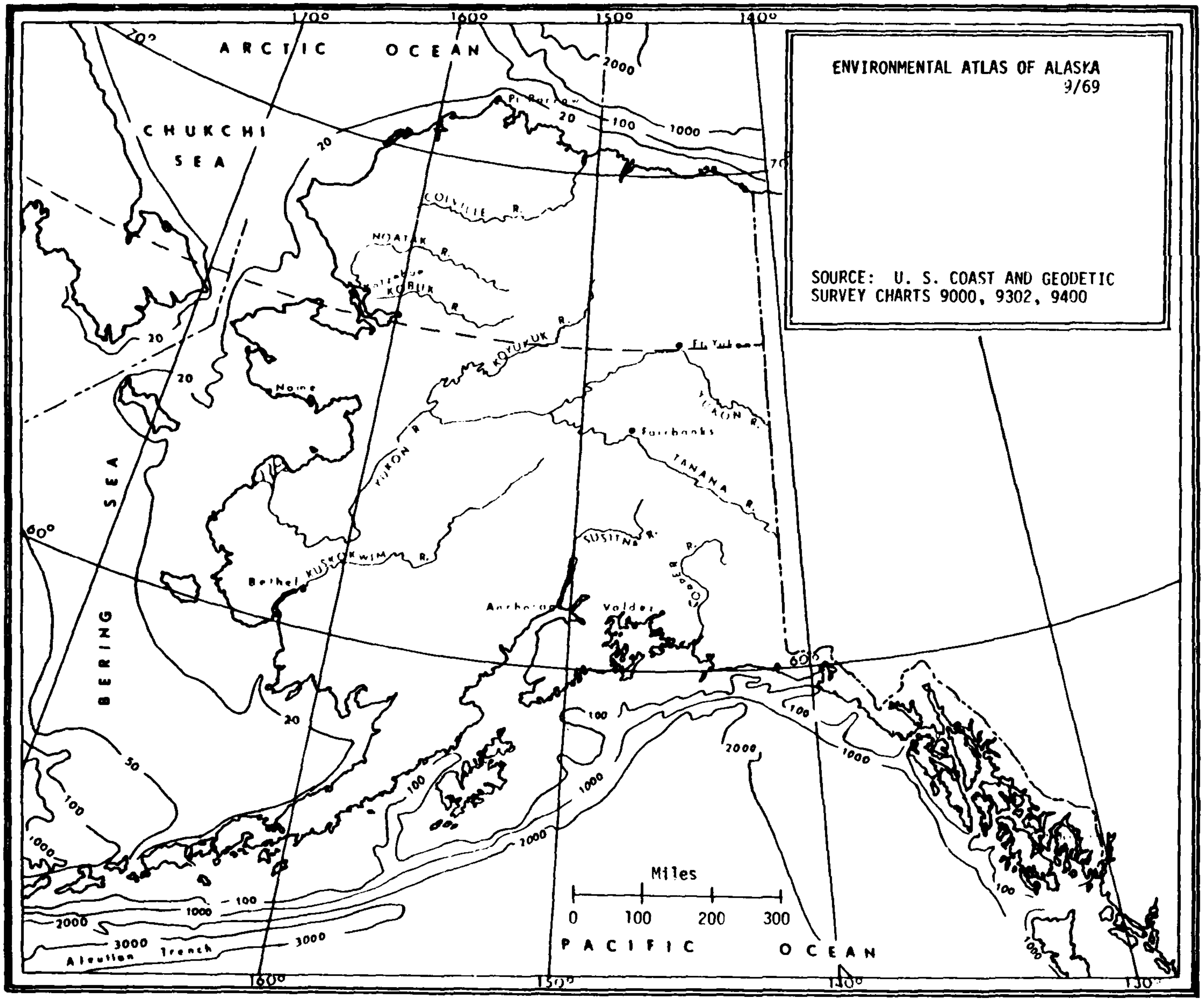


Figure 9. Depths of Alaskan coastal waters (fathoms) (from Beaufort Sea ref. 24).

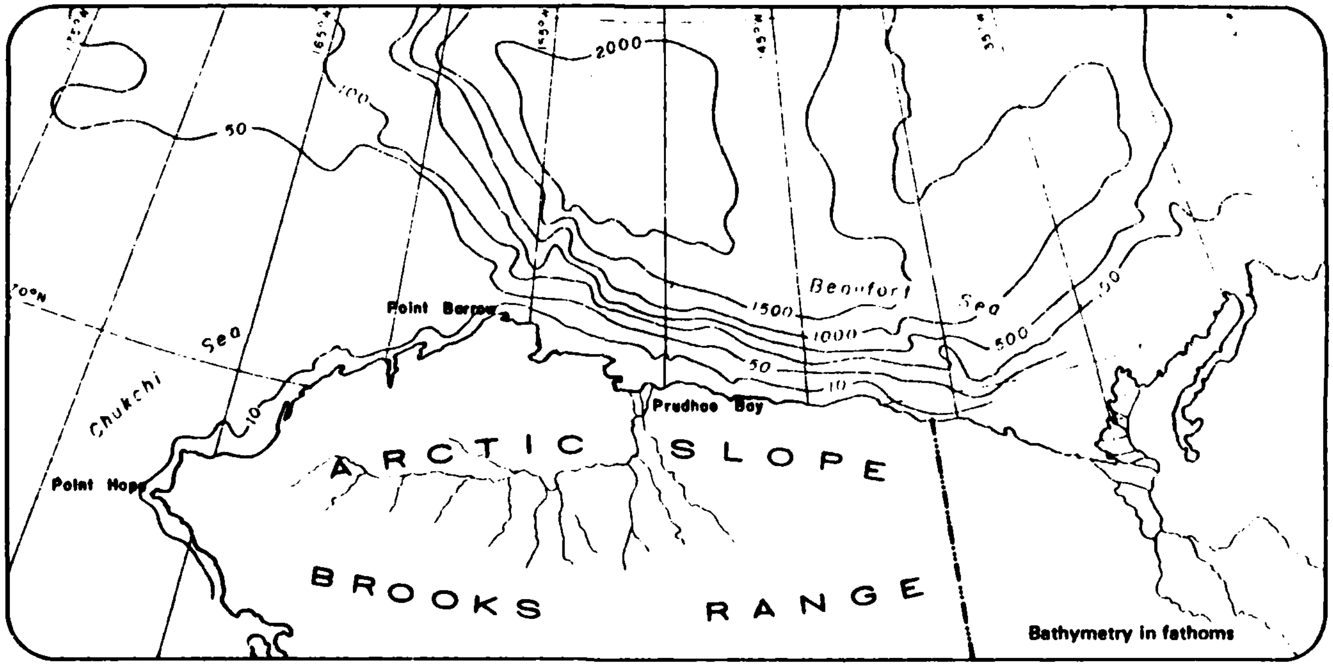


Figure 10. Bathymetry of the Chukchi and Beaufort Seas-north coast of Alaska (from Beaufort Sea ref. 1).

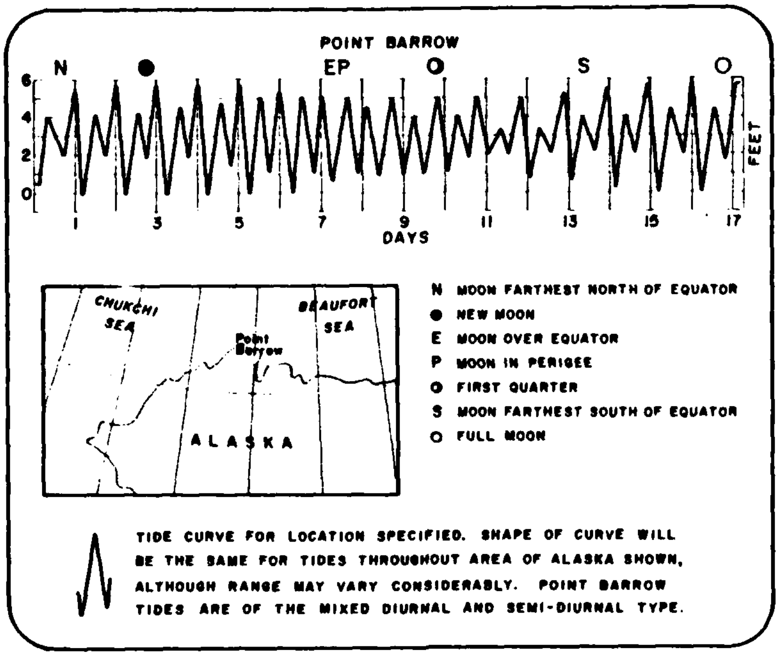


Figure 11. Tides (from Beaufort Sea ref. 1).

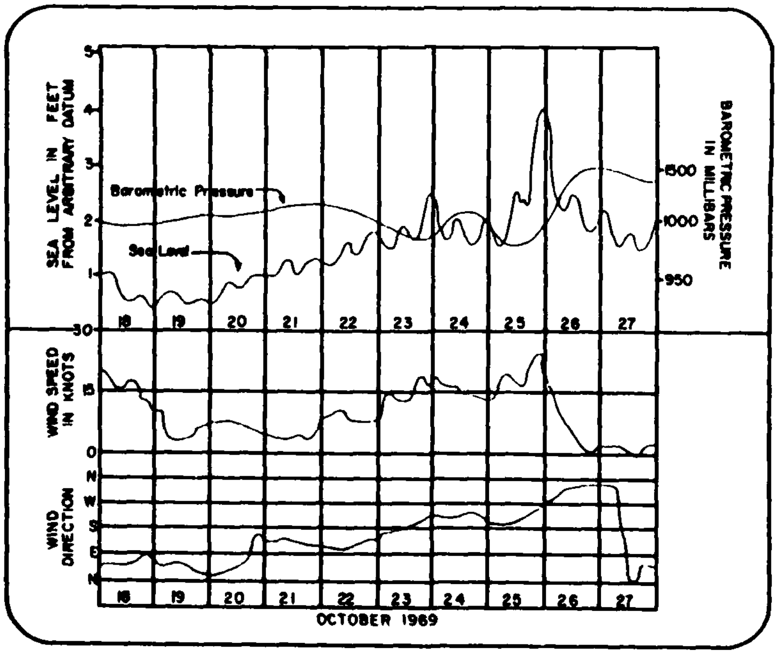
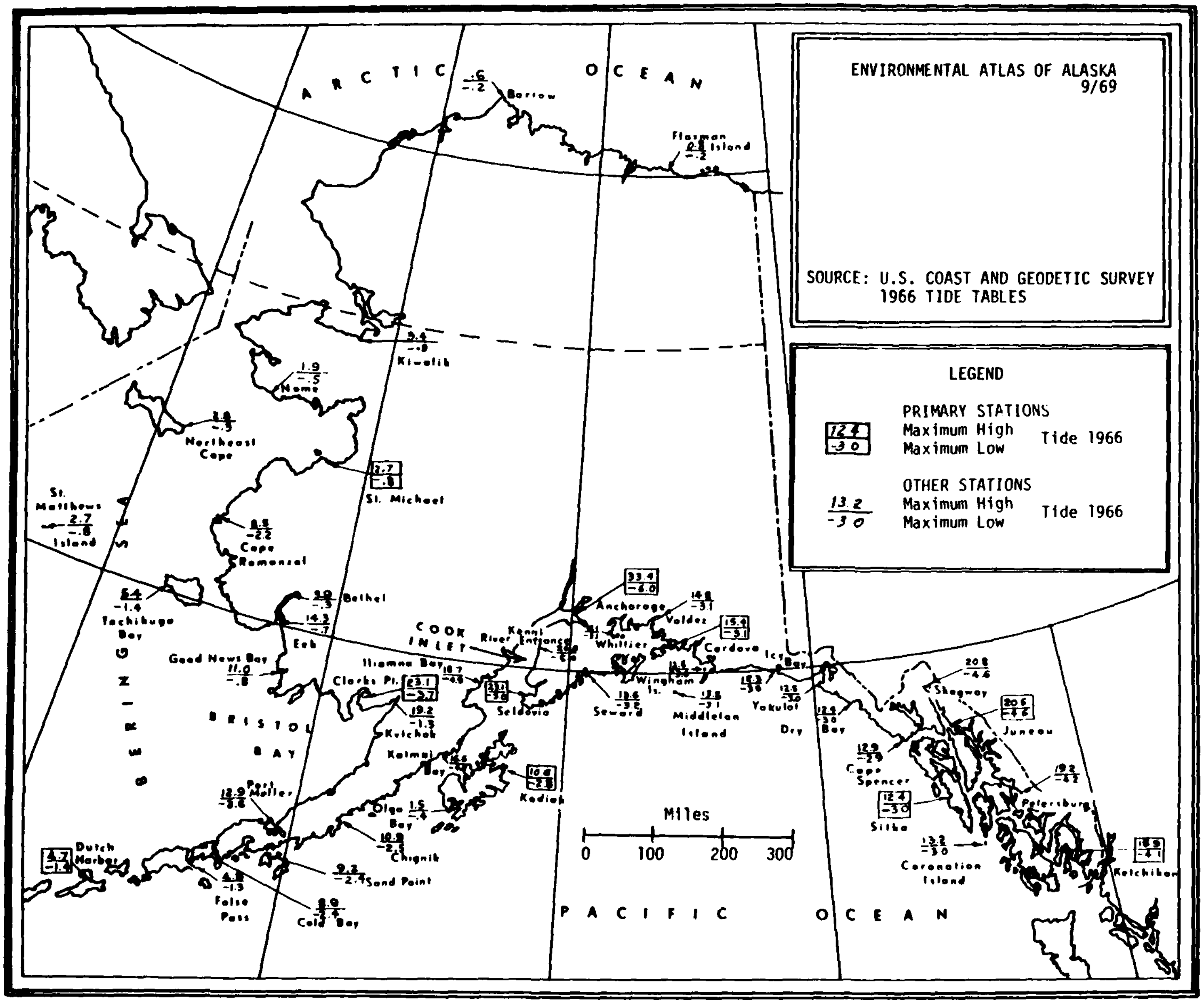


Figure 12. Sea level relationships between barometric pressure and wind speed and direction off Barrow, Alaska (from Beaufort Sea ref. 1).


ENVIRONMENTAL ATLAS OF ALASKA
9/69
SOURCE: U.S. COAST AND GEODETIC SURVEY
1966 TIDE TABLES
LEGEND
PRIMARY STATIONS
Maximum High
Maximum Low
Tide 1966
OTHER STATIONS
Maximum High
Maximum Low
Tide 1966
13.2
-3.0
ARCTIC OCEAN
PACIFIC OCEAN
BERING SEA
BRISTOL BAY
COOK INLET
Miles
0
100
200
300
Barrow
Flaxman Island
Kiwalik
Nome
Northeast Cape
St. Michael
St. Matthews Island
Cape Romanzof
Bethel
Tachikuga Bay
Eek
Good News Bay
Iliamna Bay
Clarks Pt.
Kvichak
Kenai River Entrance
Anchorage
Valdez
Whittier
Cordova
Icy Bay
Seldovia
Seward
Wingham Is.
Middleton Island
Yakutat
Dry Bay
Katmai Bay
Kodiak
Olga Bay
Chignik
Sand Point
Port Moller
Dutch Harbor
False Pass
Cold Bay
Skagway
Juneau
Cape Spencer
Sitka
Petersburg
Coronation Island
Ketchikan

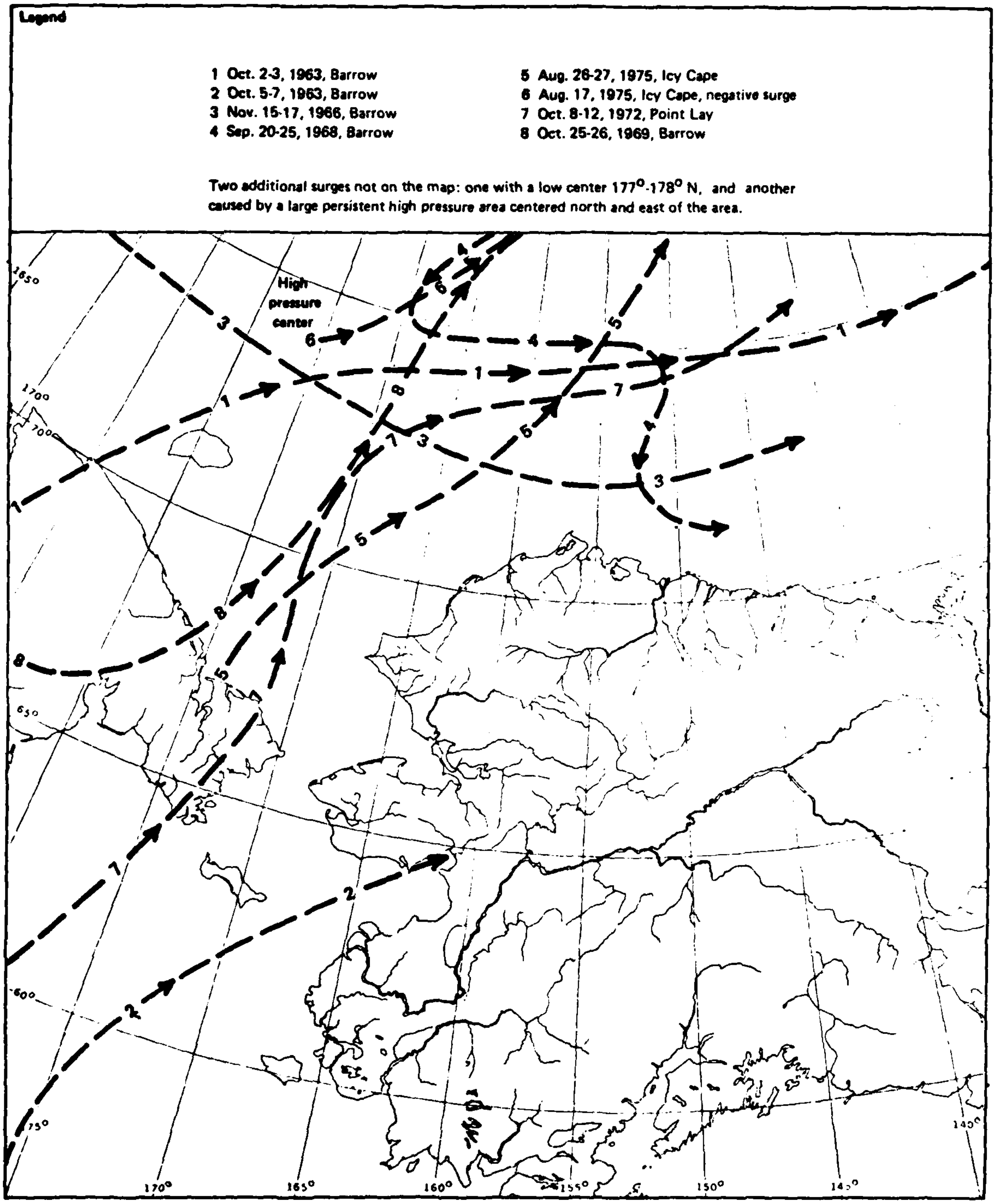


Figure 14. Storm surge occurrences (from Beaufort Sea ref 2).

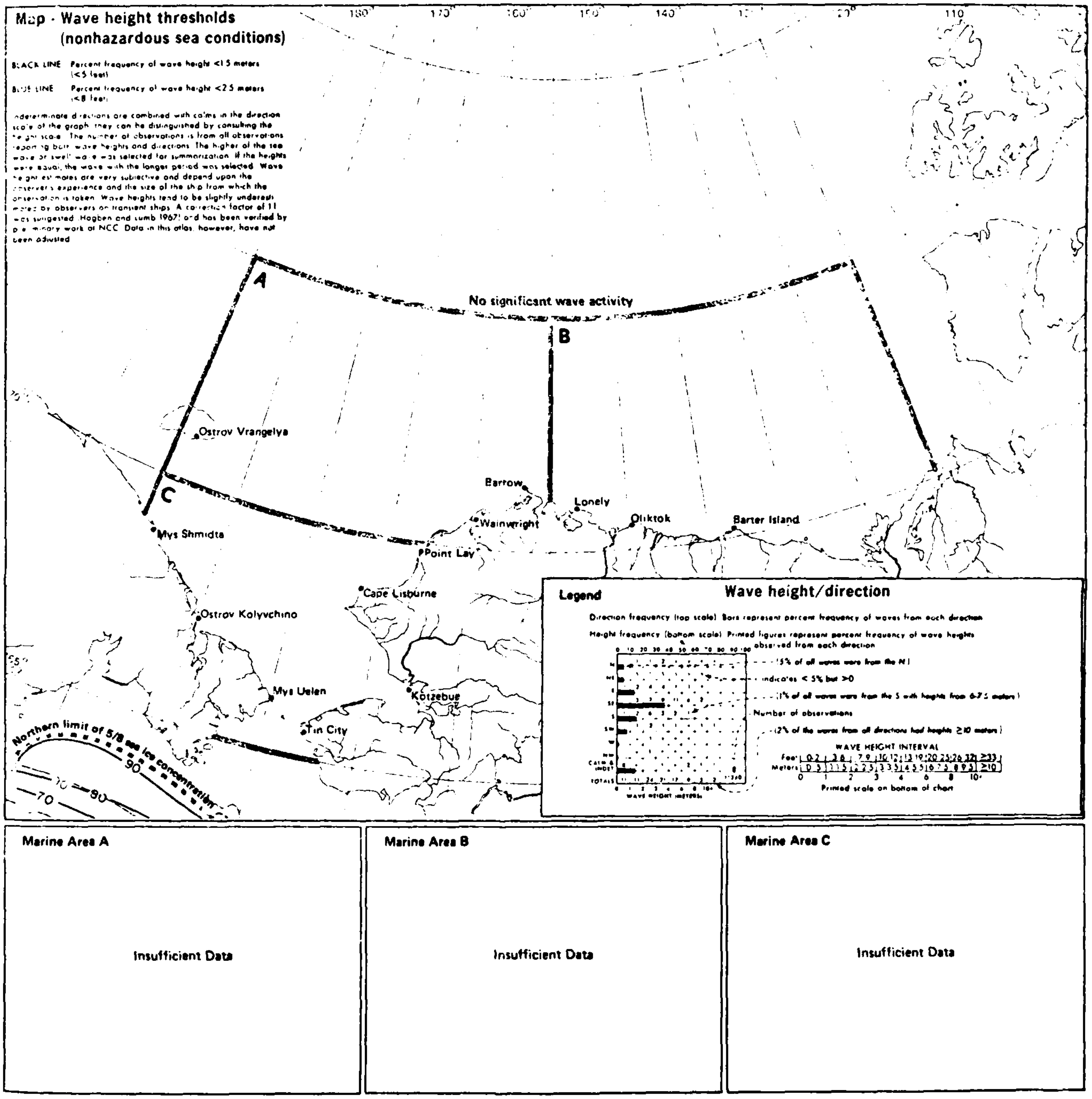


Figure 15. Wave height thresholds (nonhazardous), January (from Beaufort Sea ref. 2).

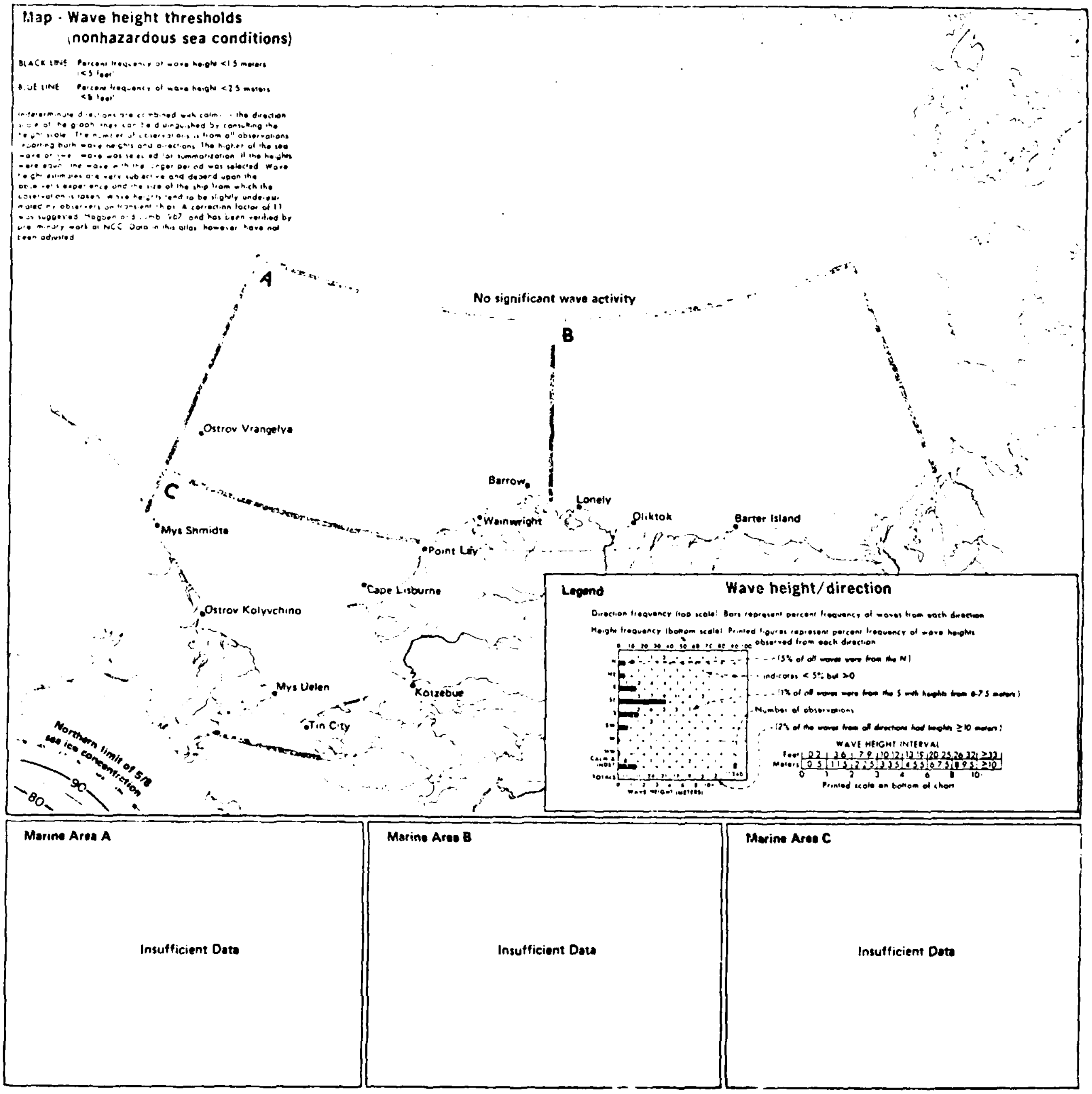


Figure 16. Wave height thresholds (nonhazardous), February (from Beaufort Sea ref. 2).

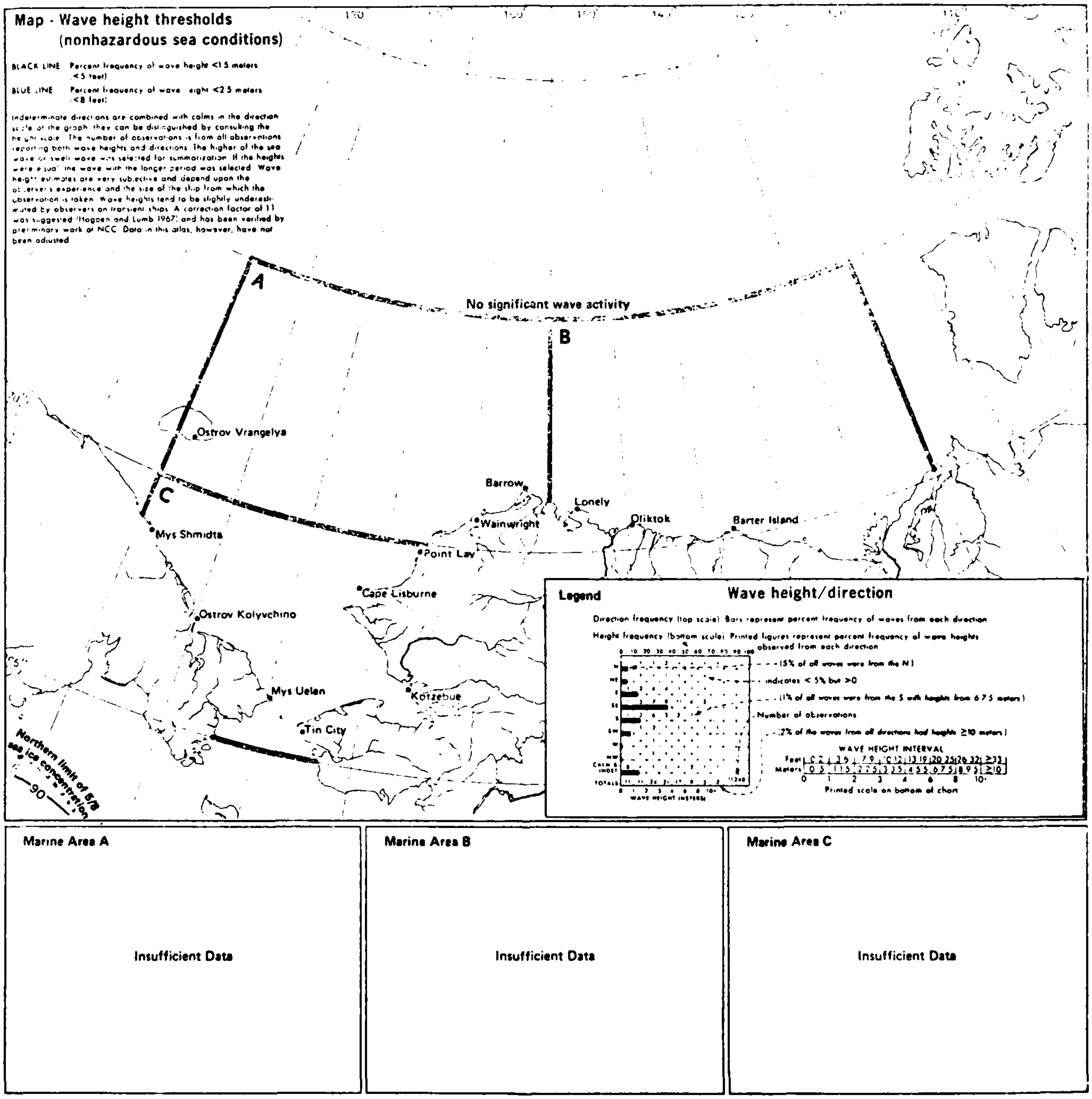


Figure 17. Wave height thresholds (nonhazardous), March (from Beaufort Sea ref. 2).

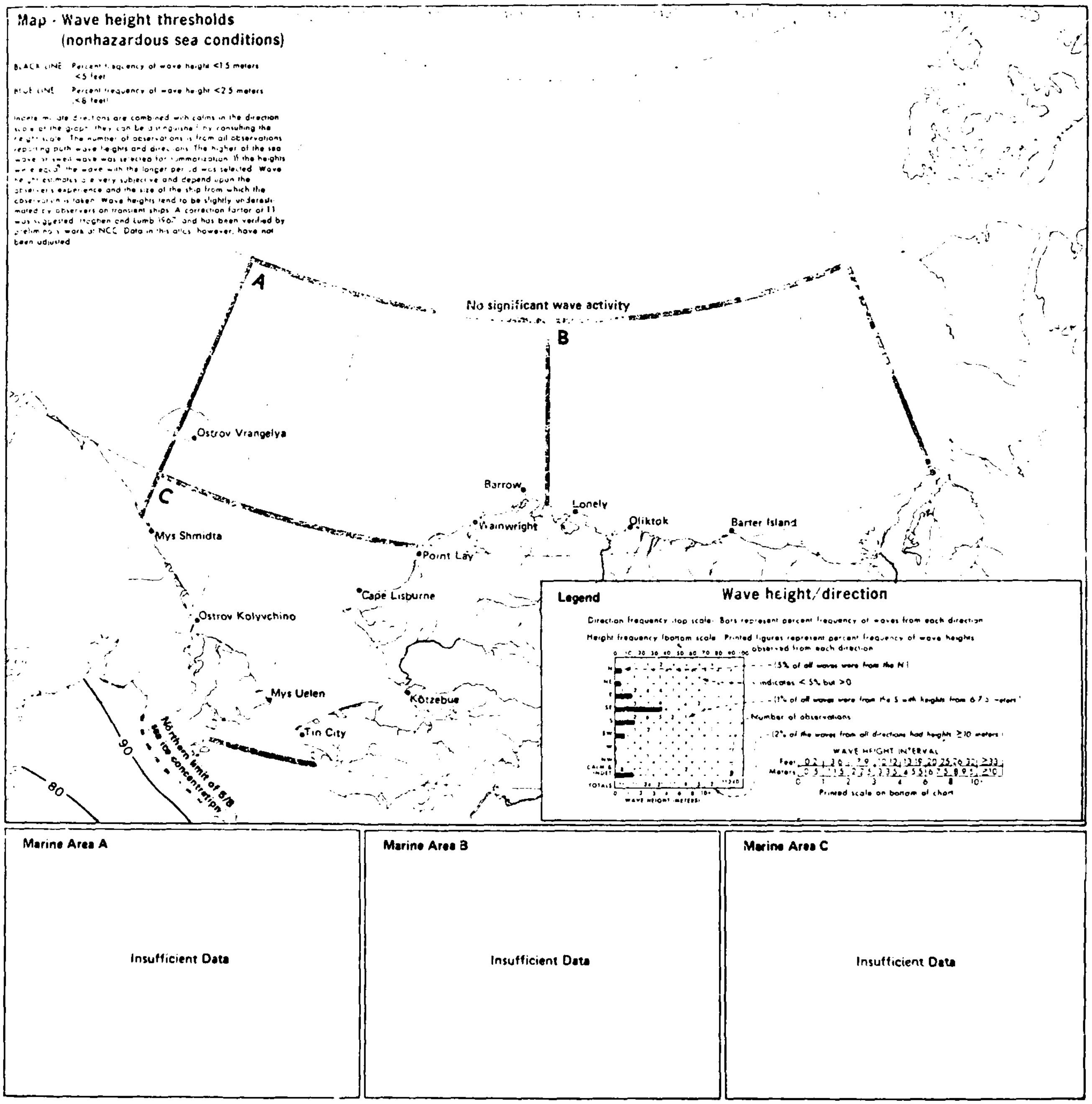


Figure 18. Wave height thresholds (nonhazardous), April (from Beaufort Sea ref. 2).

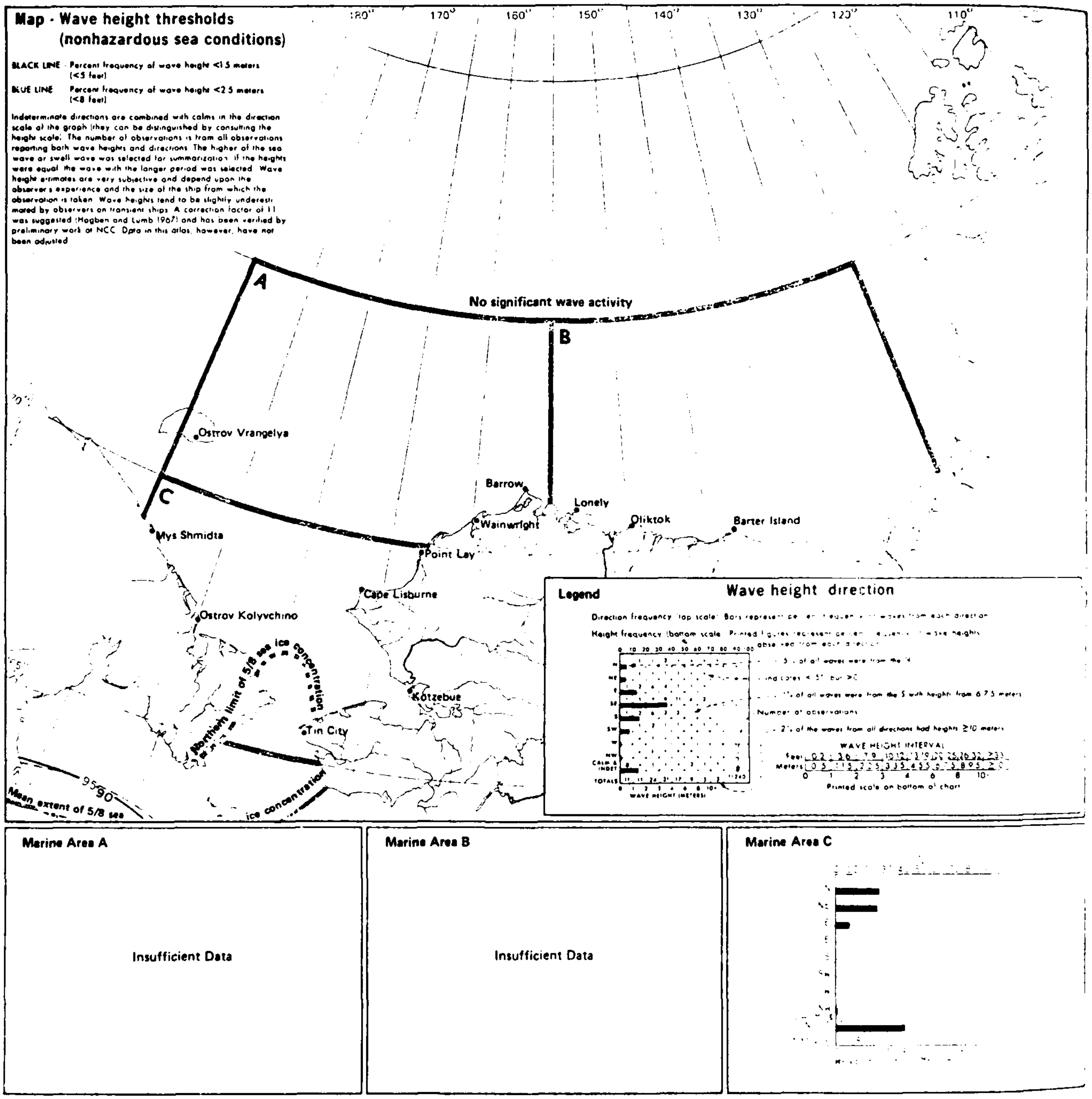


Figure 19. Wave height thresholds (nonhazardous), May (from Beaufort Sea ref. 2).

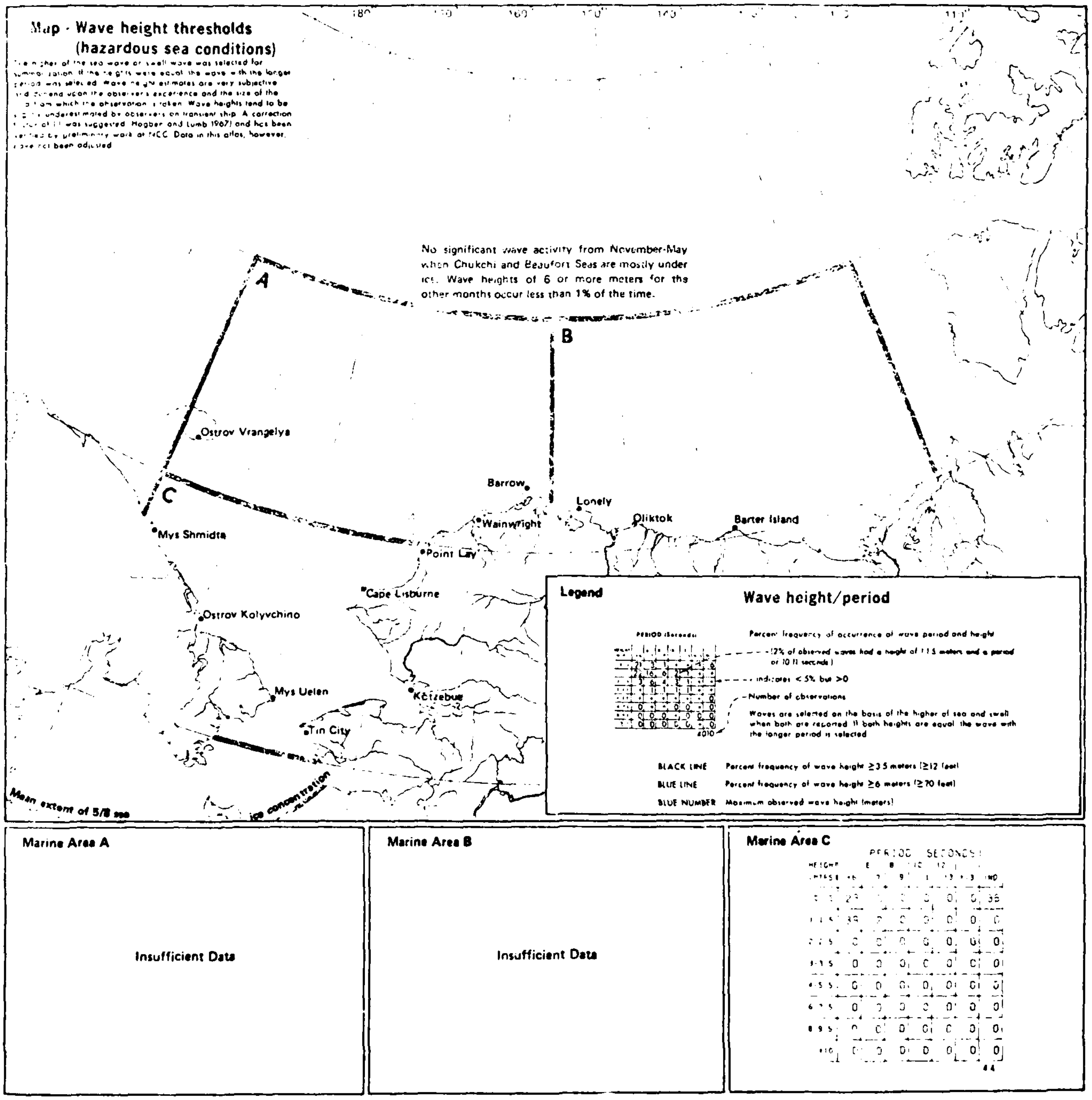


Figure 20. Wave height thresholds (hazardous), May (from Beaufort Sea ref. 2).

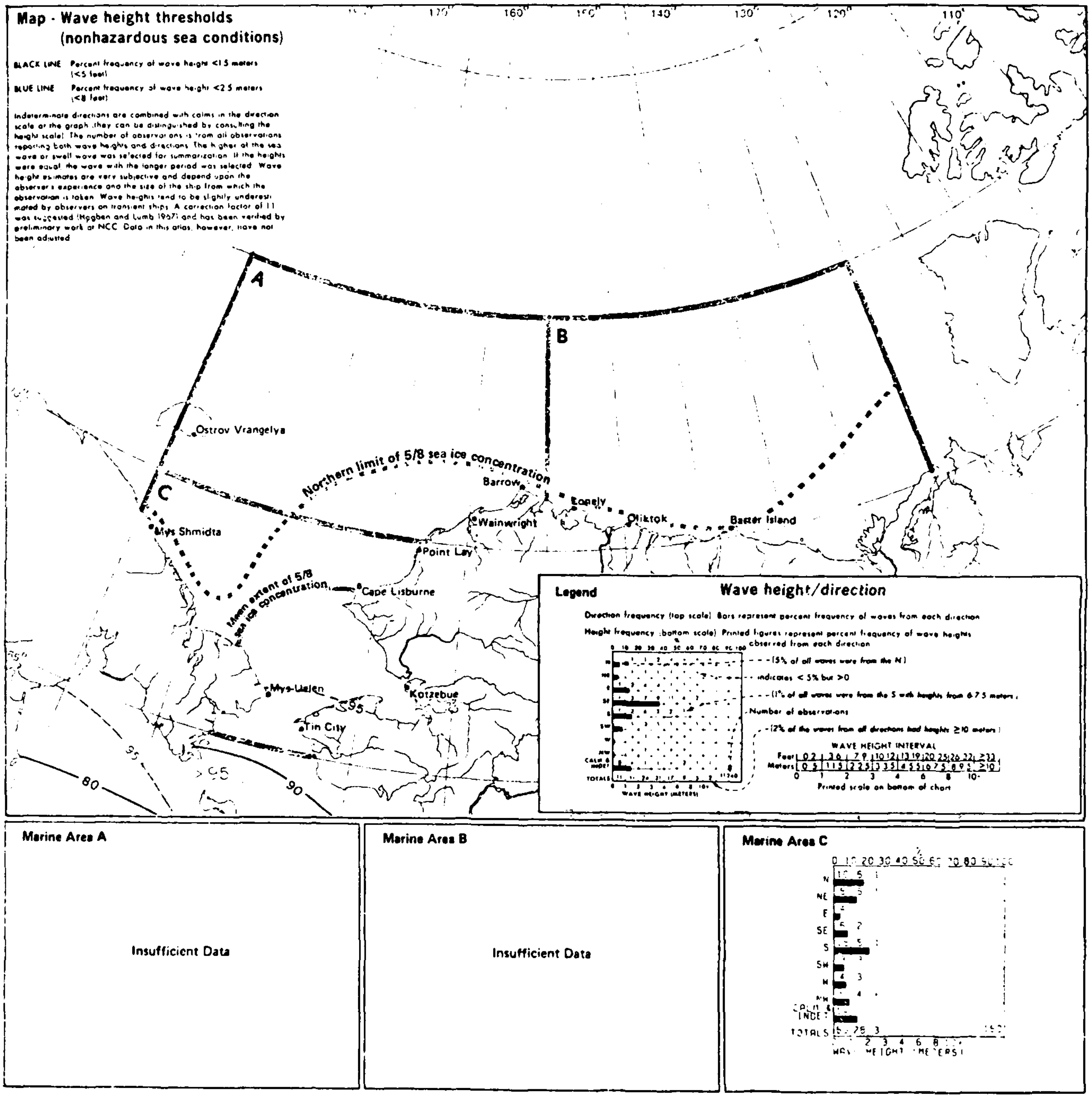


Figure 21. Wave height thresholds (nonhazardous), June (from Beaufort Sea ref. 2).

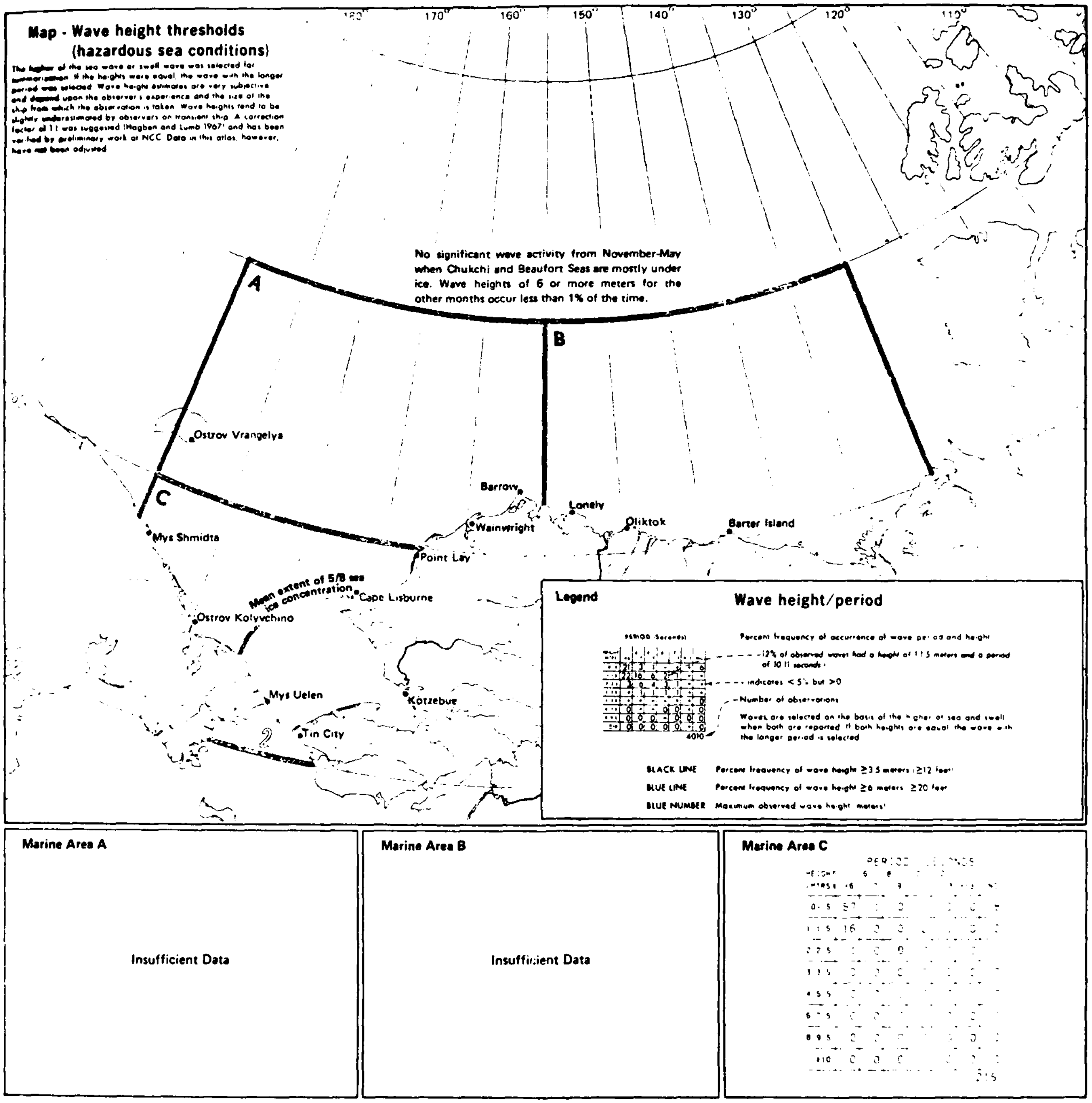


Figure 22. Wave height thresholds (hazardous), June (from Beaufort Sea ref. 2).

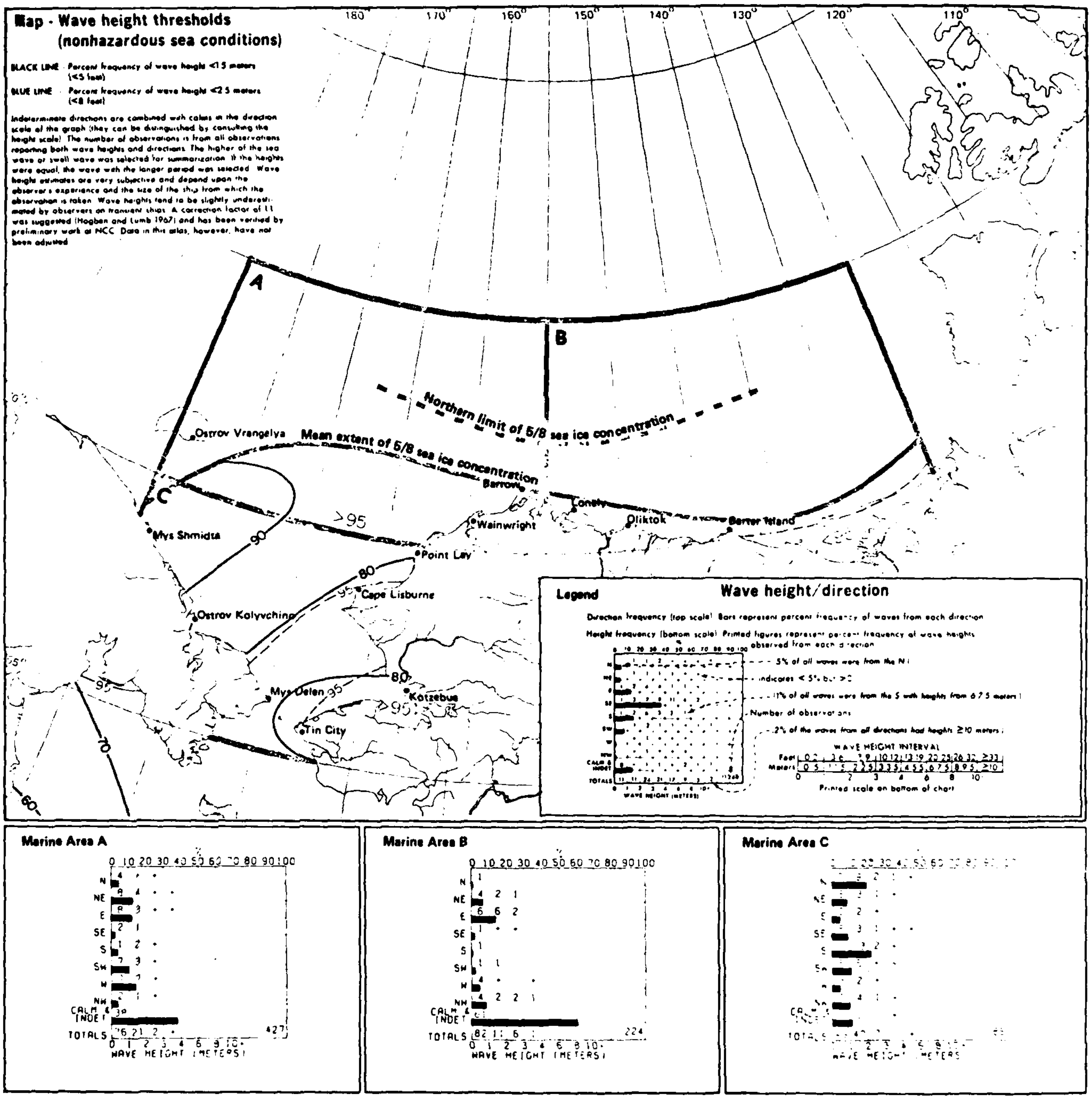
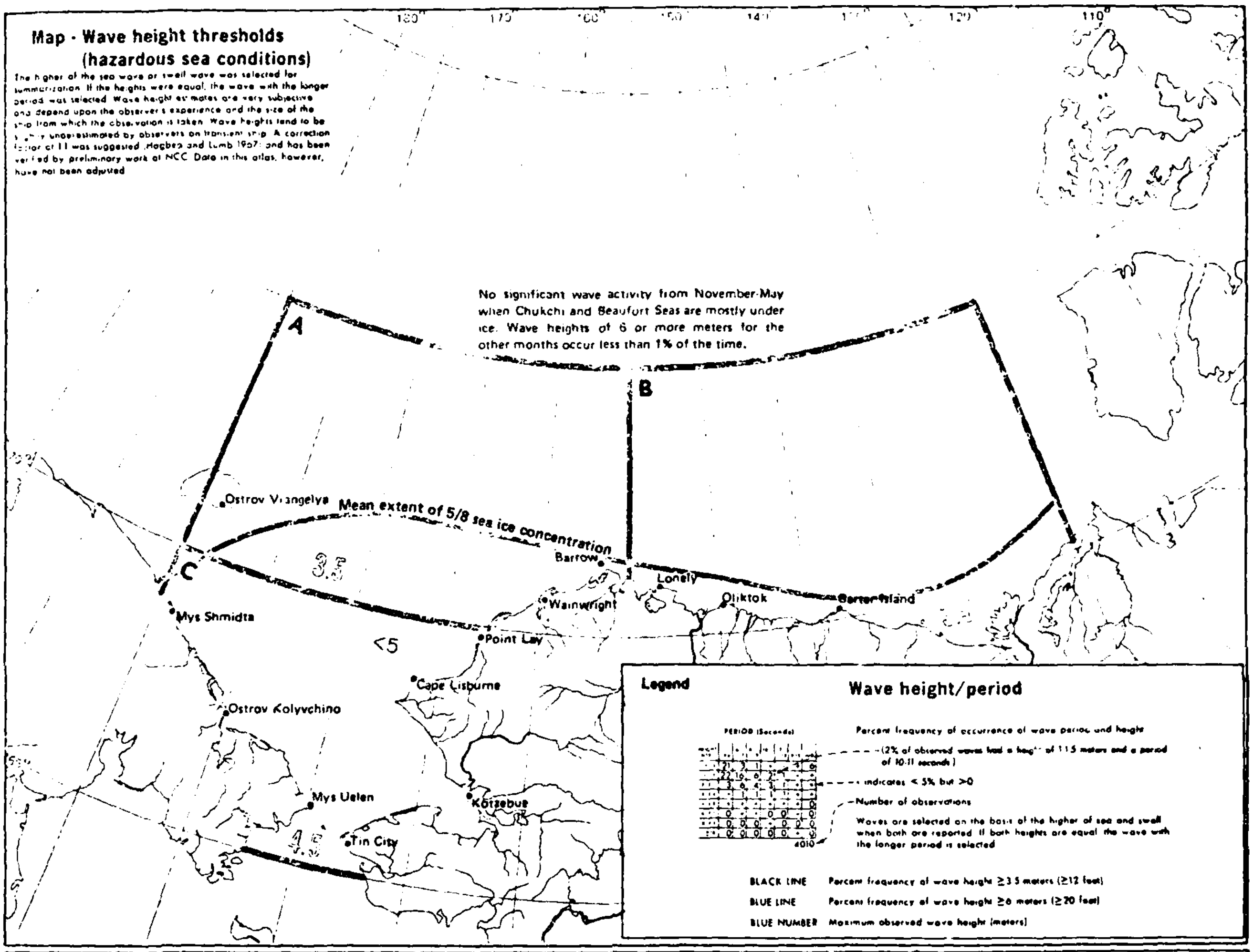


Figure 23. Wave height thresholds (nonhazardous), July (from Beaufort Sea ref. 2).



Marine Area A

HEIGHT (METERS)	PERIOD (SECONDS) <6	6-7	8-9	10-11	12-13	>13	IND
0-.5	42	3	•	•	0	0	38
1-1.5	8	6	1	1	0	0	•
2-2.5	1	•	1	•	0	0	0
3-3.5	•	0	0	0	0	0	0
4-5.5	0	0	0	0	0	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0
							586

Marine Area B

HEIGHT (METERS)	PERIOD (SECONDS) <6	6-7	8-9	10-11	12-13	>13	IND
0-.5	39	0	0	0	0	0	48
1-1.5	7	1	0	0	0	0	0
2-2.5	4	0	0	0	0	0	0
3-3.5	1	0	0	0	0	0	0
4-5.5	0	0	0	0	0	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0
							296

Marine Area C

HEIGHT (METERS)	PERIOD (SECONDS) <6	6-7	8-9	10-11	12-13	>13	IND
0-.5	40	3	1	•	0	0	13
1-1.5	24	8	1	•	1	0	3
2-2.5	2	2	1	•	•	0	1
3-3.5	1	•	•	•	0	0	0
4-5.5	•	•	0	•	0	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0
							1369

Figure 24. Wave height thresholds (hazardous), July (from Beaufort Sea ref. 2)

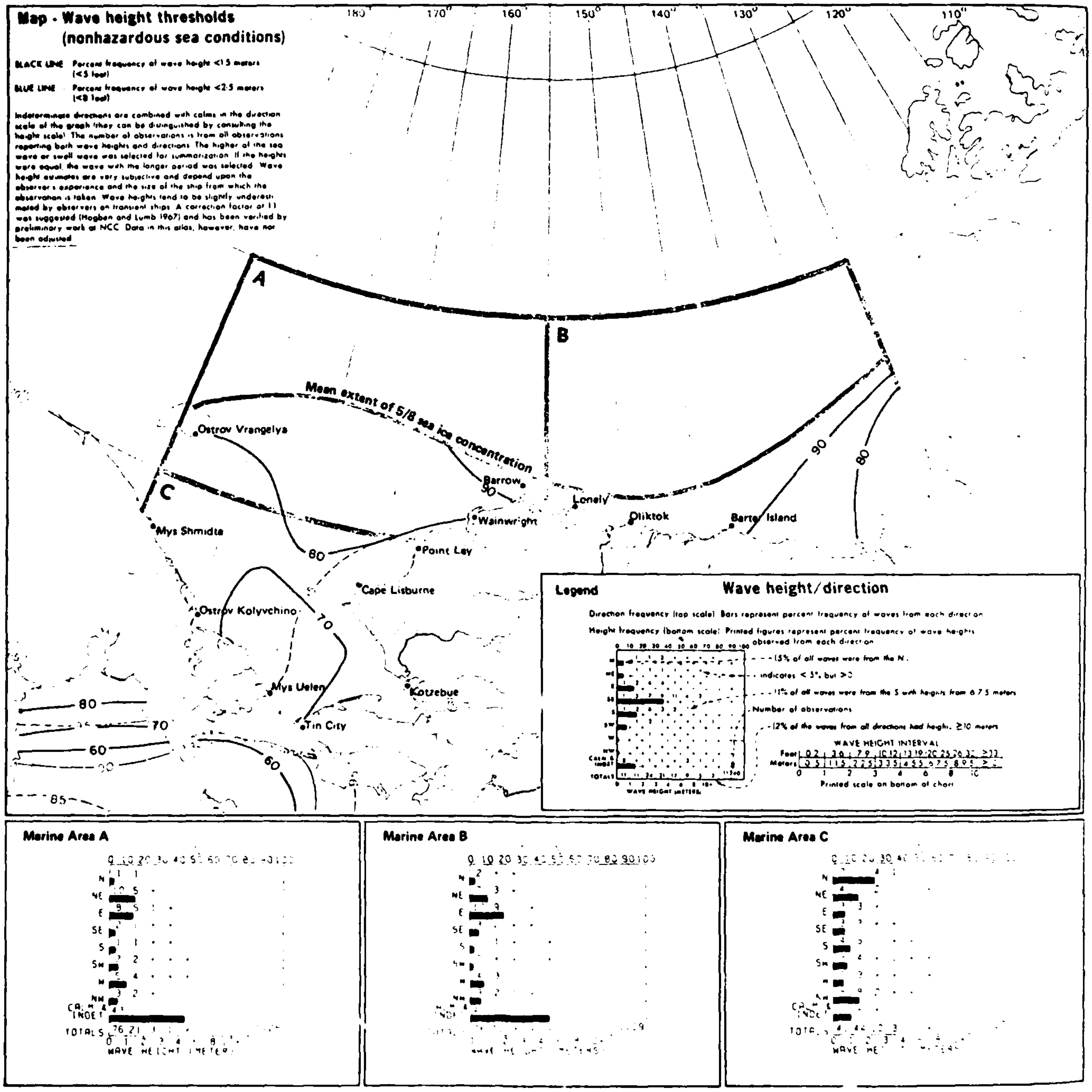
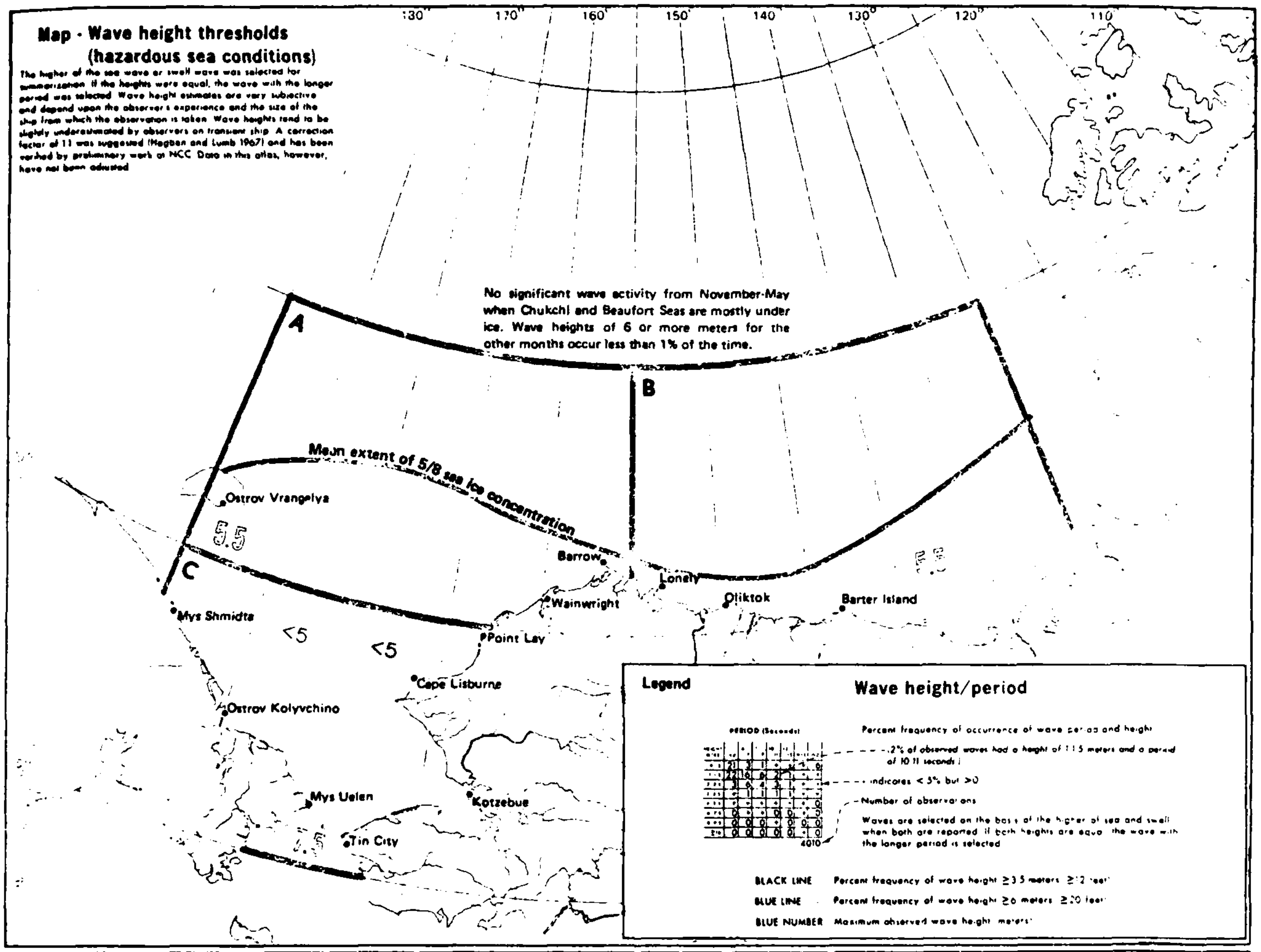


Figure 25. Wave height thresholds (nonhazardous), August (from Beaufort Sea ref. 2).



Marine Area A

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	INO
0-.5	42	[illegible]	1	•	0	0	36
1-1.5	12	4	1	•	•	•	•
2-2.5	•	[illegible]	•	0	0	•	•
3-3.5	•	•	•	0	0	0	0
4-5.5	0	0	0	•	0	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

1393

Marine Area B

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	INO
0-.5	45	•	•	•	0	0	36
1-1.5	13	3	•	0	•	0	0
2-2.5	2	•	1	0	0	0	0
3-3.5	•	0	0	0	0	0	0
4-5.5	•	0	0	0	0	•	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

1418

Marine Area C

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	INC
0-.5	31	[illegible]	•	•	[illegible]	0	14
1-1.5	25	5	2	•	[illegible]	•	4
2-2.5	3	3	1	•	•	0	[illegible]
3-3.5	1	•	1	[illegible]	•	•	[illegible]
4-5.5	•	•	•	•	[illegible]	•	0
6-7.5	0	•	0	[illegible]	[illegible]	•	•
8-9.5	0	[illegible]	0	[illegible]	[illegible]	0	0
≥10	0	[illegible]	0	[illegible]	[illegible]	0	0

1218

Figure 26. Wave height thresholds (hazardous), August (from Beaufort Sea ref. 2).

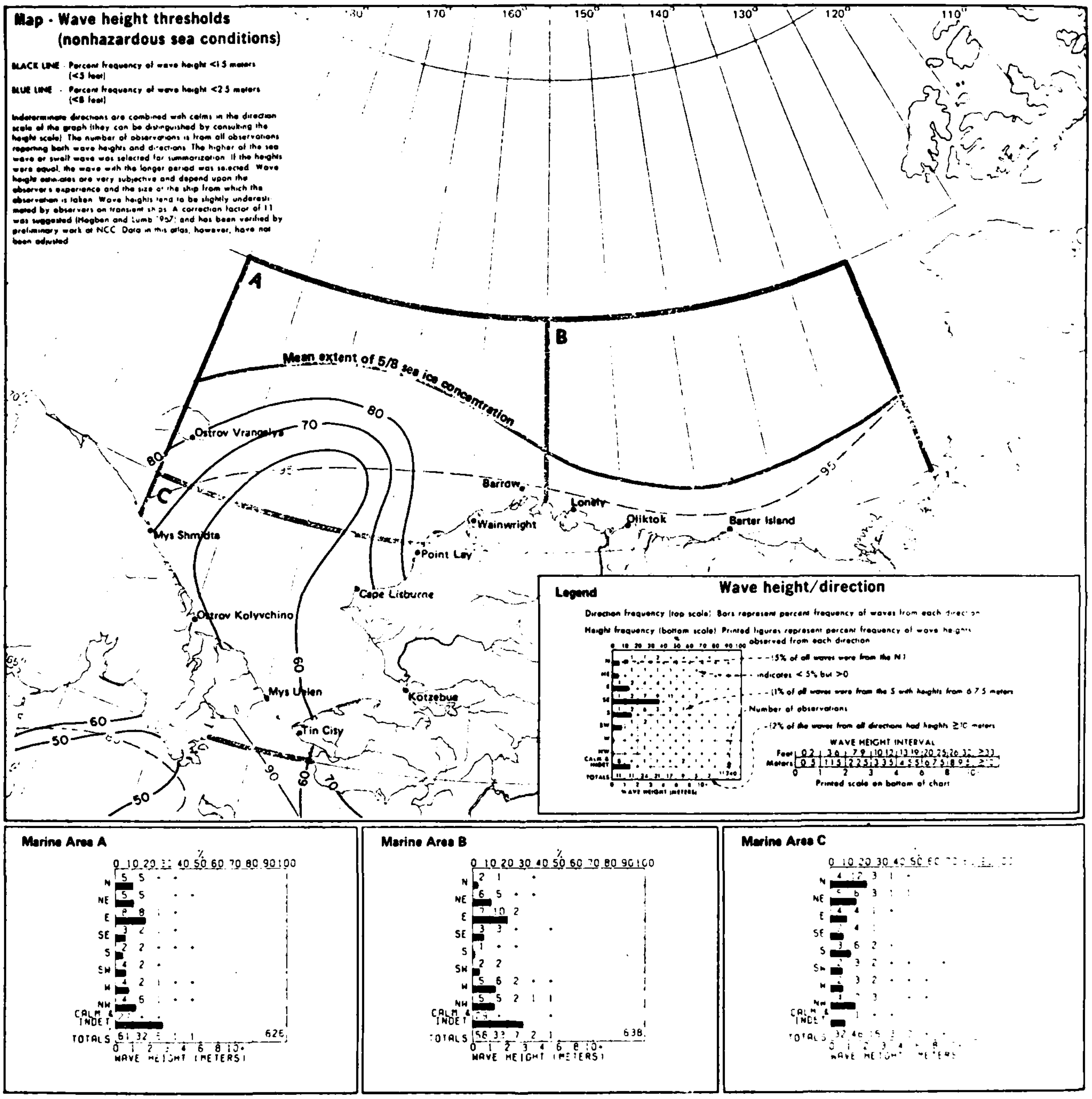
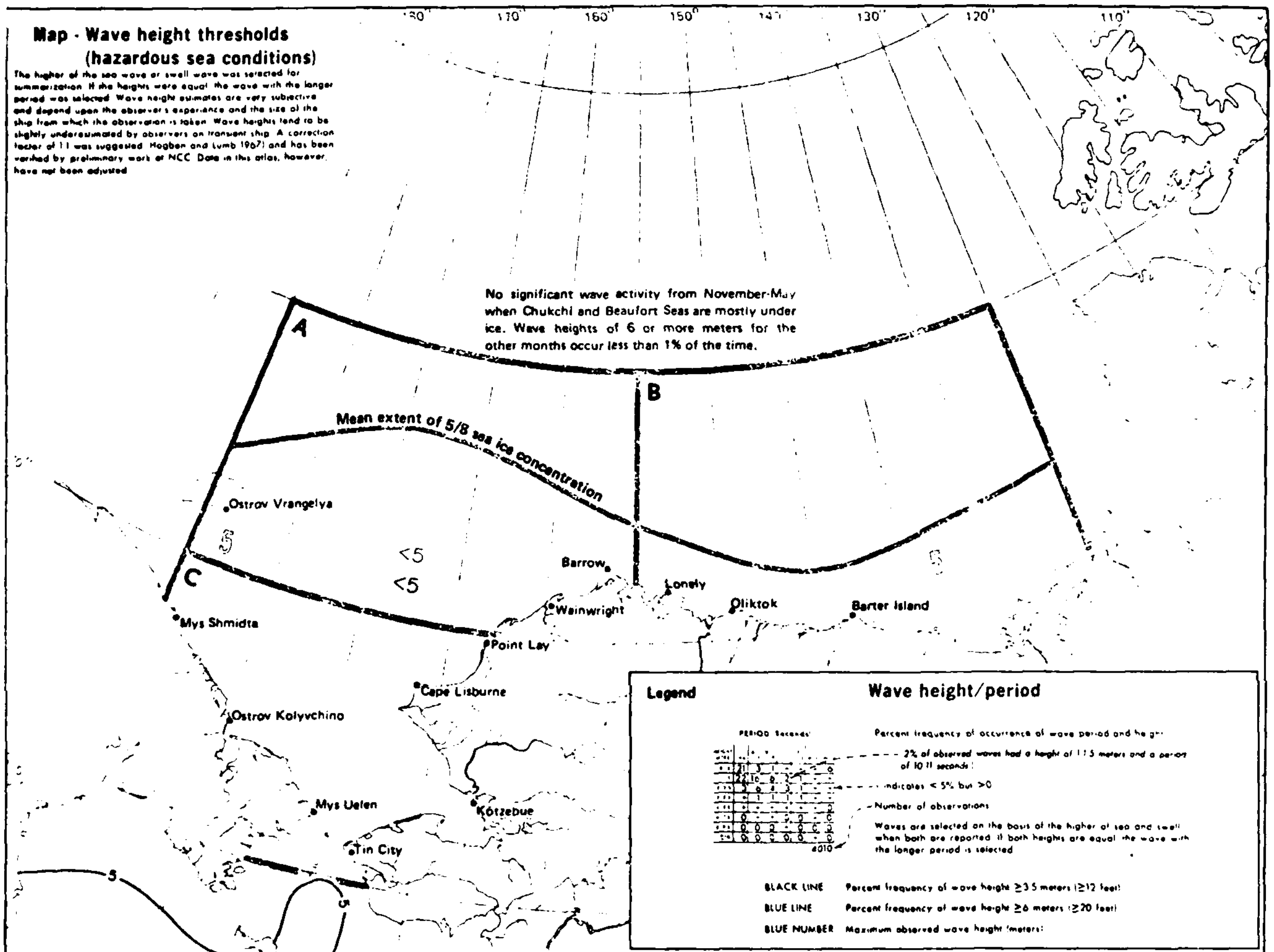


Figure 27. Wave height thresholds (nonhazardous), September (from Beaufort Sea ref. 2).



Marine Area A

PERIOD (SECONDS)

HEIGHT (METERS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	41	1	•	•	0	0	25
1-1.5	21	2	2	•	•	•	1
2-2.5	1	2	•	0	•	•	•
3-3.5	[illegible]	•	0	0	0	•	0
4-5.5	0	•	•	0	0	•	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

749

Marine Area B

PERIOD (SECONDS)

HEIGHT (METERS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	42	1	•	1	0	0	25
1-1.5	20	2	1	1	•	•	0
2-2.5	4	1	0	0	0	0	0
3-3.5	•	1	0	0	•	0	0
4-5.5	•	•	0	0	0	•	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

856

Marine Area C

PERIOD (SECONDS)

HEIGHT (METERS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	24	0	•	•	0	[illegible]	[illegible]
1-1.5	31	9	2	•	•	0	[illegible]
2-2.5	5	6	2	[illegible]	0	•	[illegible]
3-3.5	[illegible]	[illegible]	•	[illegible]	•	[illegible]	•
4-5.5	•	[illegible]	•	•	•	0	[illegible]
6-7.5	0	•	0	0	0	0	[illegible]
8-9.5	0	•	0	0	[illegible]	0	[illegible]
≥10	0	0	0	0	0	0	[illegible]

[illegible]

Figure 28. Wave height thresholds (hazardous), September (from Beaufort Sea ref. 2).

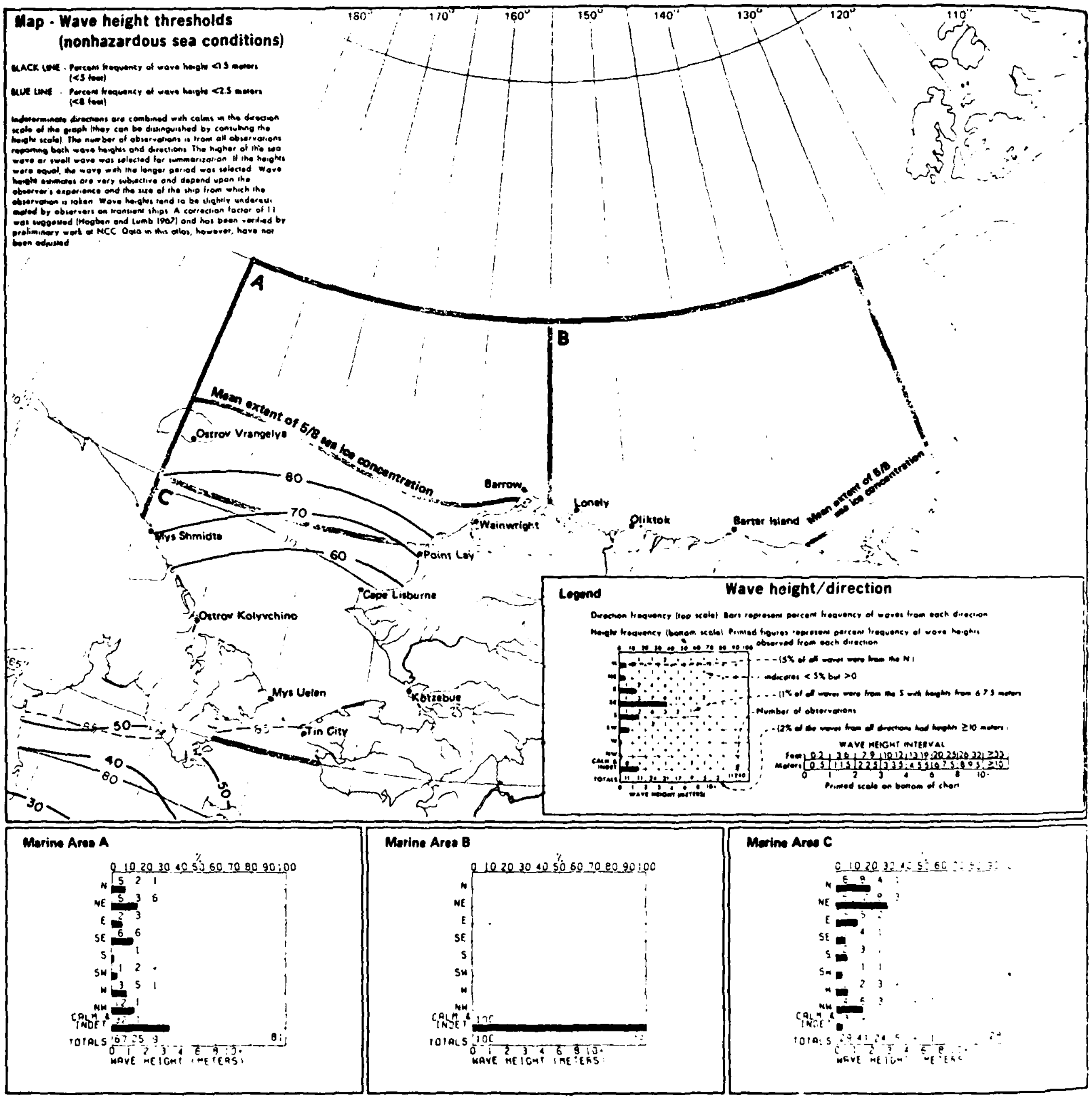
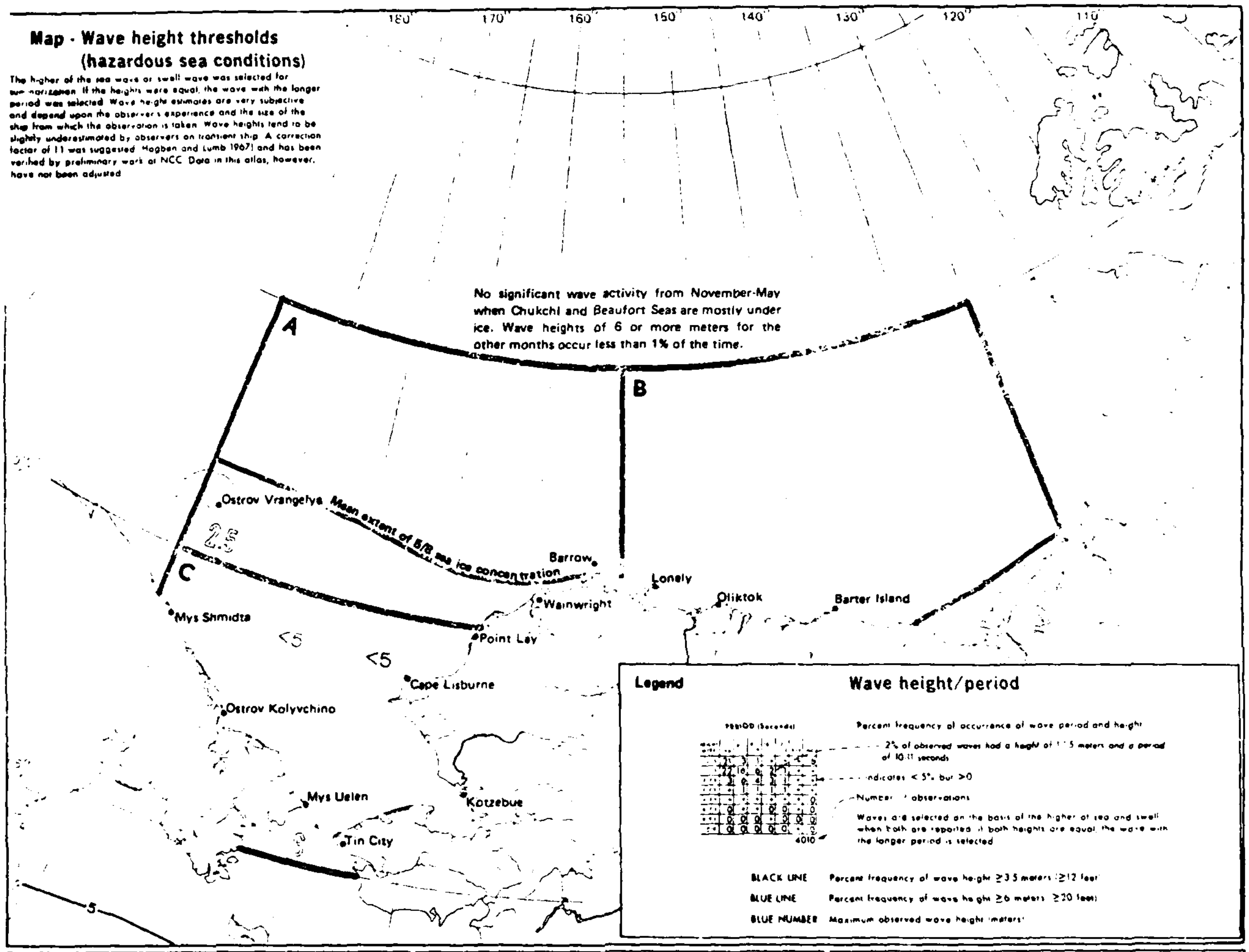


Figure 29. Wave height thresholds (nonhazardous), October (from Beaufort Sea ref. 2).



Marine Area A

PERIOD (SECONDS)

HEIGHT (METERS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	44	2	0	0	0	0	27
1-1.5	12	6	1	0	0	0	1
2-2.5	6	0	1	0	0	0	0
3-3.5	0	0	0	0	0	0	0
4-5.5	0	0	0	0	0	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

98

Marine Area B

Insufficient Data

Marine Area C

PERIOD (SECONDS)

HEIGHT (METERS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	30	•	•	[illegible]	[illegible]	[illegible]	[illegible]
1-1.5	31	3	1	[illegible]	1	•	[illegible]
2-2.5	13	4	3	[illegible]	[illegible]	[illegible]	[illegible]
3-3.5	[illegible]	•	3	•	0	[illegible]	[illegible]
4-5.5	0	•	0	[illegible]	[illegible]	[illegible]	[illegible]
6-7.5	0	•	0	•	0	[illegible]	[illegible]
8-9.5	[illegible]	0	0	[illegible]	0	[illegible]	[illegible]
≥10	0	0	[illegible]	[illegible]	0	[illegible]	0

3?4

Figure 30. Wave height thresholds (hazardous), October (from Beaufort Sea ref. 2).

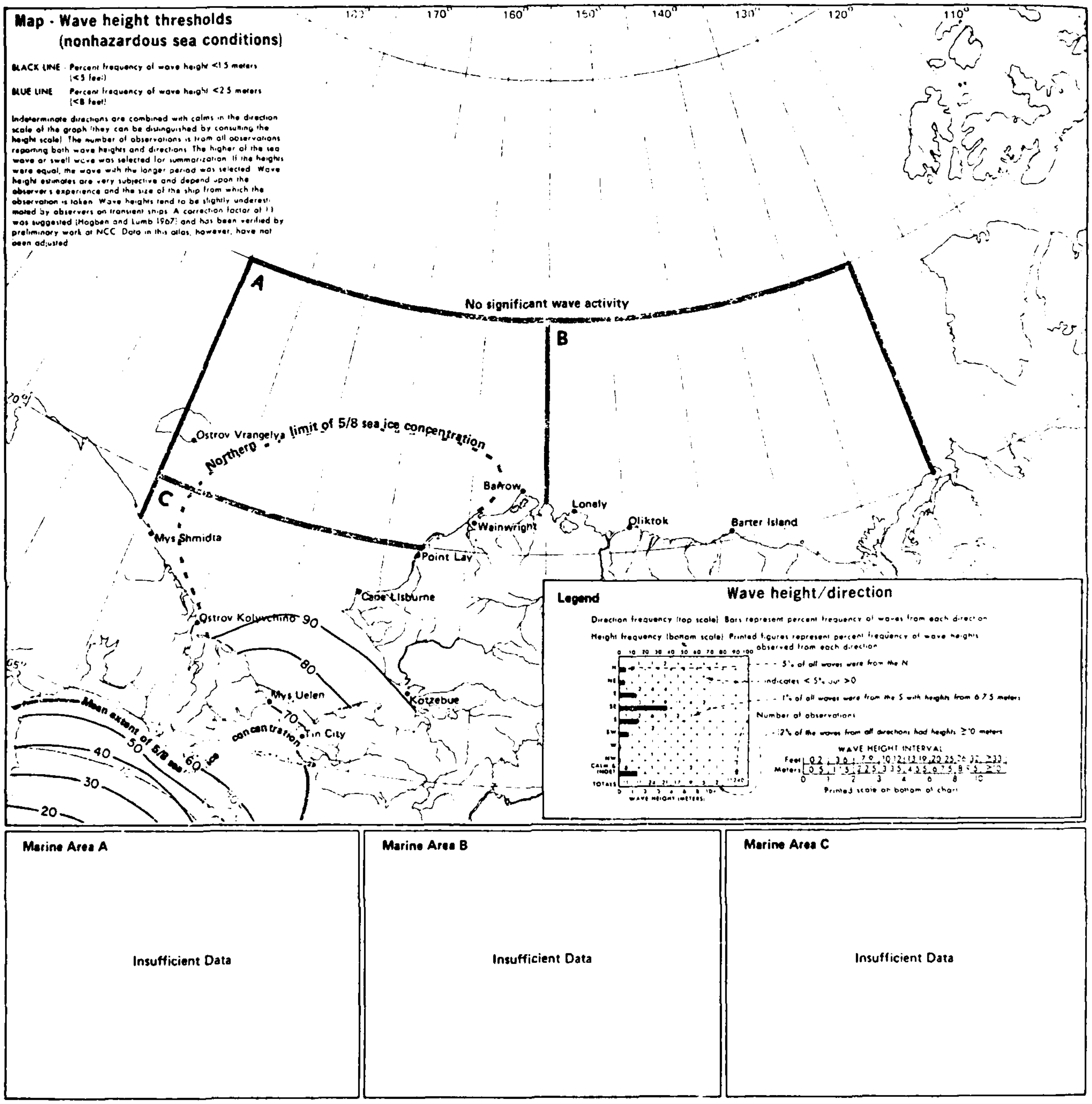


Figure 31. Wave height thresholds (nonhazardous), November (from Beaufort Sea ref. 2).

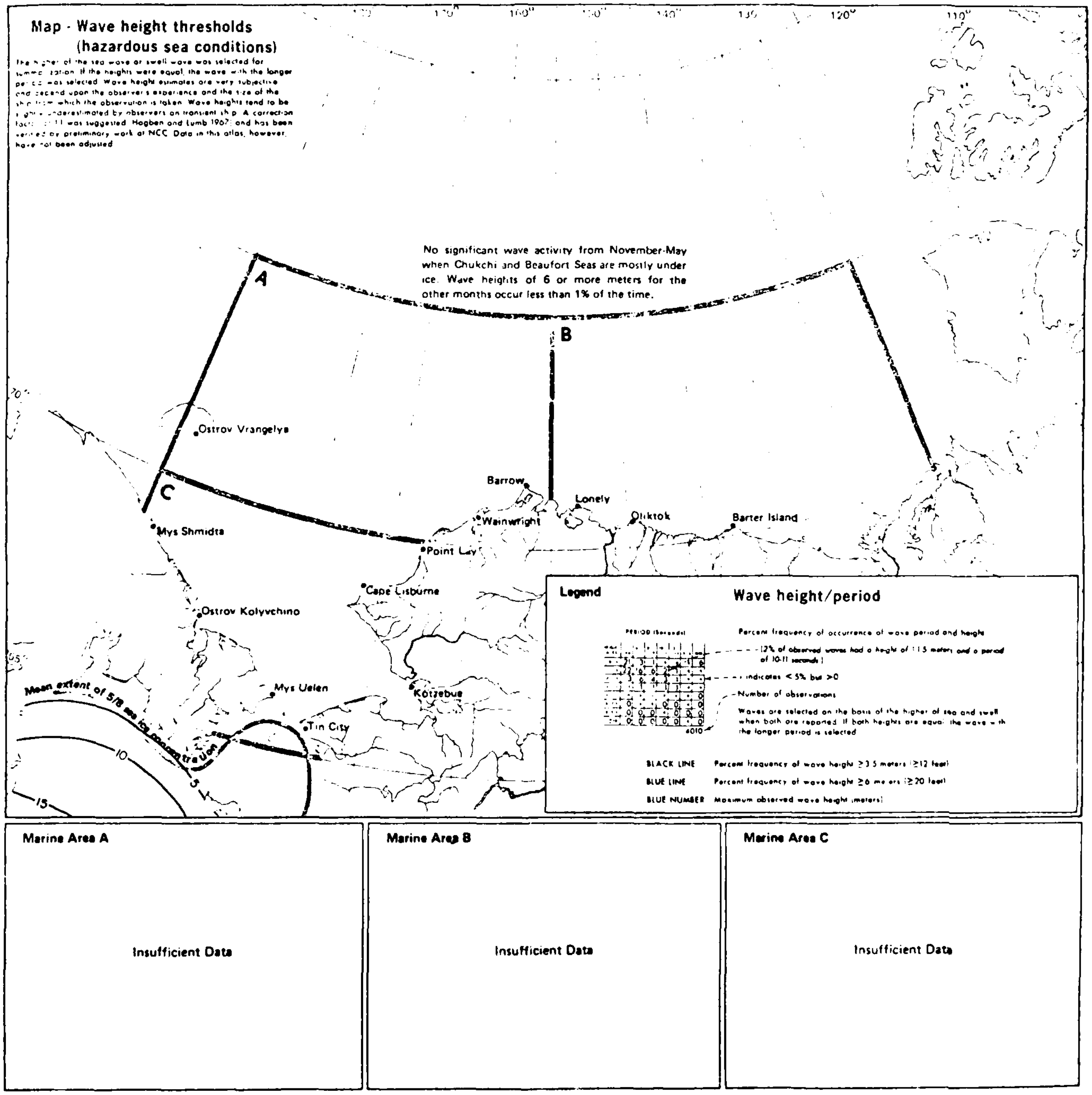


Figure 32. Wave height thresholds (hazardous), November (from Beaufort Sea ref. 2).

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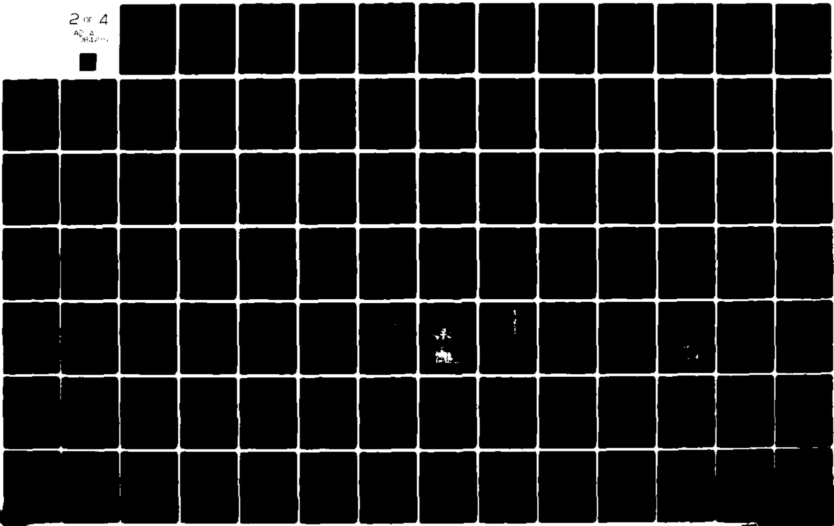
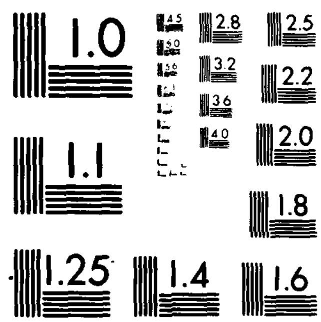




MICROCOPY RESOLUTION TEST CHART

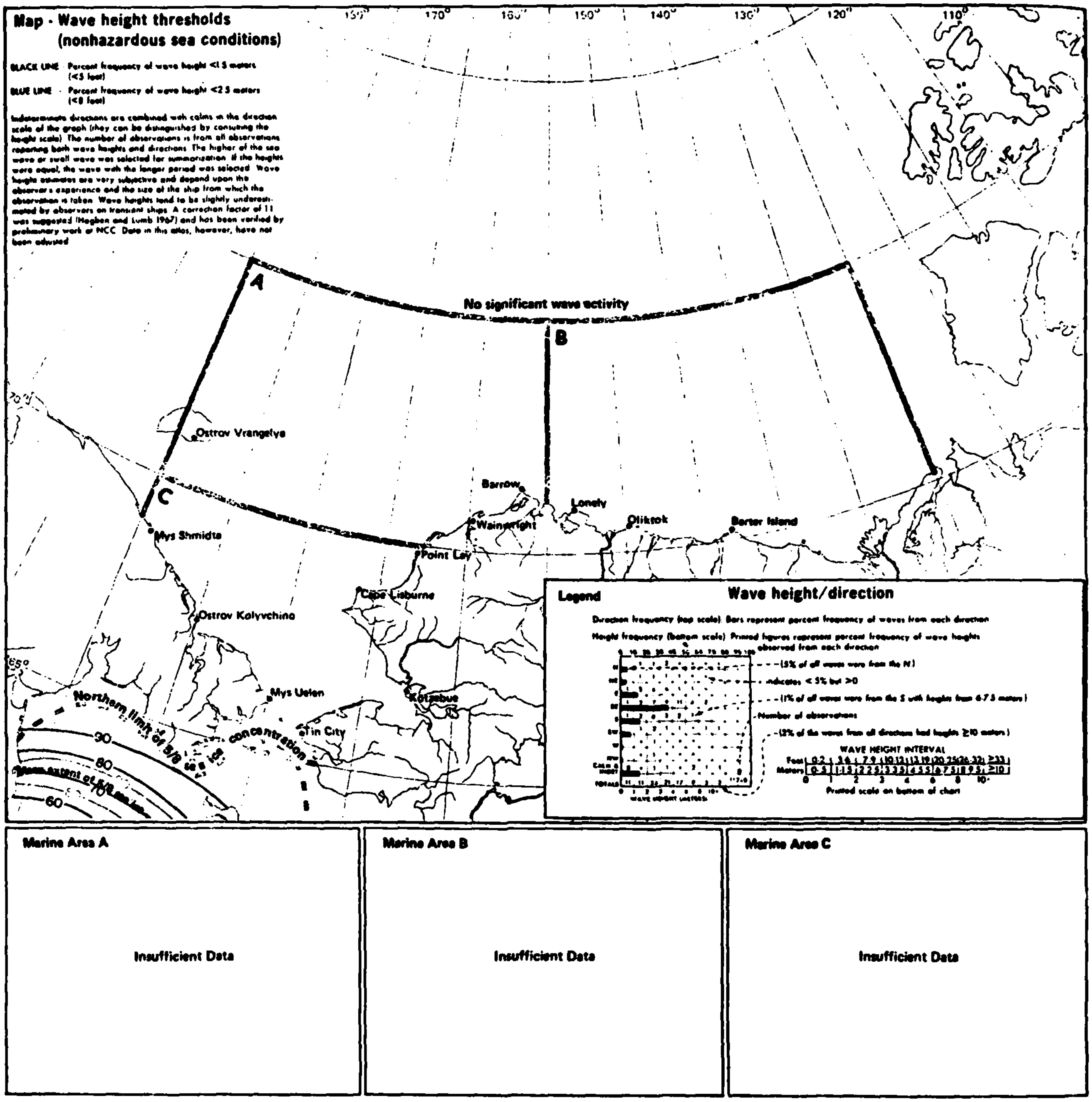
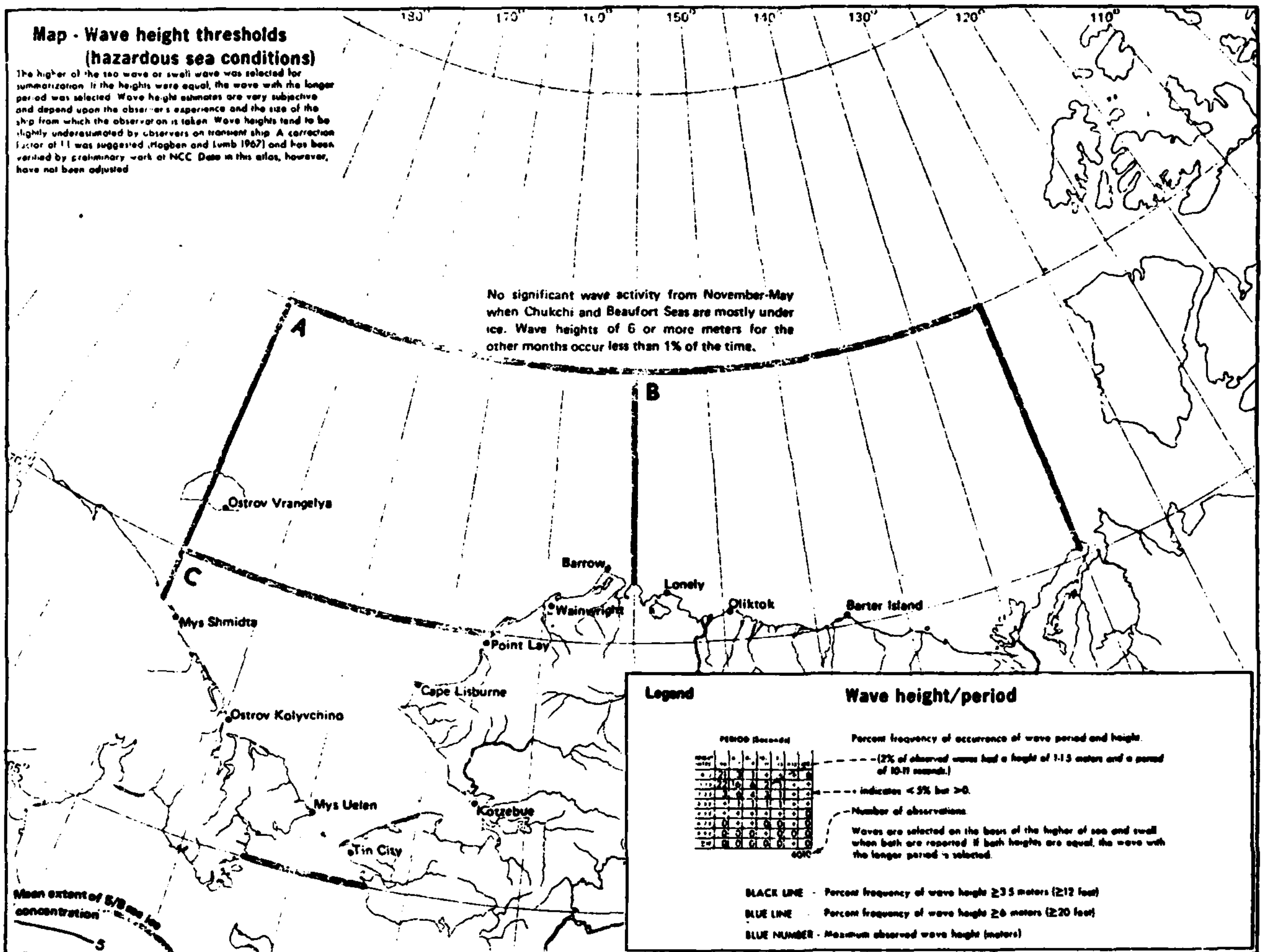


Figure 33. Wave height thresholds (nonhazardous), December (from Beaufort Sea ref. 2).



Marine Area A	Marine Area B	Marine Area C
Insufficient Data	Insufficient Data	Insufficient Data

Figure 34. Wave height thresholds (hazardous), December (from Beaufort Sea ref. 2).

Legend

Annual maximum winds and waves for selected return periods—Marine areas

Return periods for maximum sustained winds and for maximum significant and extreme wave heights are presented in tabular form for selected marine areas. Sustained winds are winds averaged over a period of one minute, the significant wave height is the average height of the highest one third of all waves (sea and swell) in view, and the extreme wave height is an empirical estimate of 1.8 times the significant wave height. Estimates presented in the tables were based primarily on methods described by Thom (see References). For example, on the average the Marine Area A can expect annual maximum sustained wind speed to exceed 97 knots once in 100 years.

Area A

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	68	11.5 (38)	20.5 (68)
10	75	13.0 (43)	23.5 (77)
25	83	15.0 (50)	28.0 (91)
50	90	17.5 (57)	31.0 (102)
100	97	19.5 (64)	35.0 (115)

Area B

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	57	10.0 (33)	18.0 (59)
10	62	11.0 (37)	20.5 (67)
25	69	13.0 (43)	24.0 (78)
50	75	15.0 (49)	27.0 (88)
100	81	17.0 (55)	30.0 (99)

Area C

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	67	12.0 (39)	21.5 (70)
10	73	13.5 (44)	24.0 (79)
25	82	16.0 (52)	28.5 (93)
50	88	17.5 (58)	31.5 (104)
100	96	20.0 (65)	35.5 (117)

Figure 35. Annual maximum winds and waves for selected return periods-Marine areas (from Beaufort Sea ref. 2).

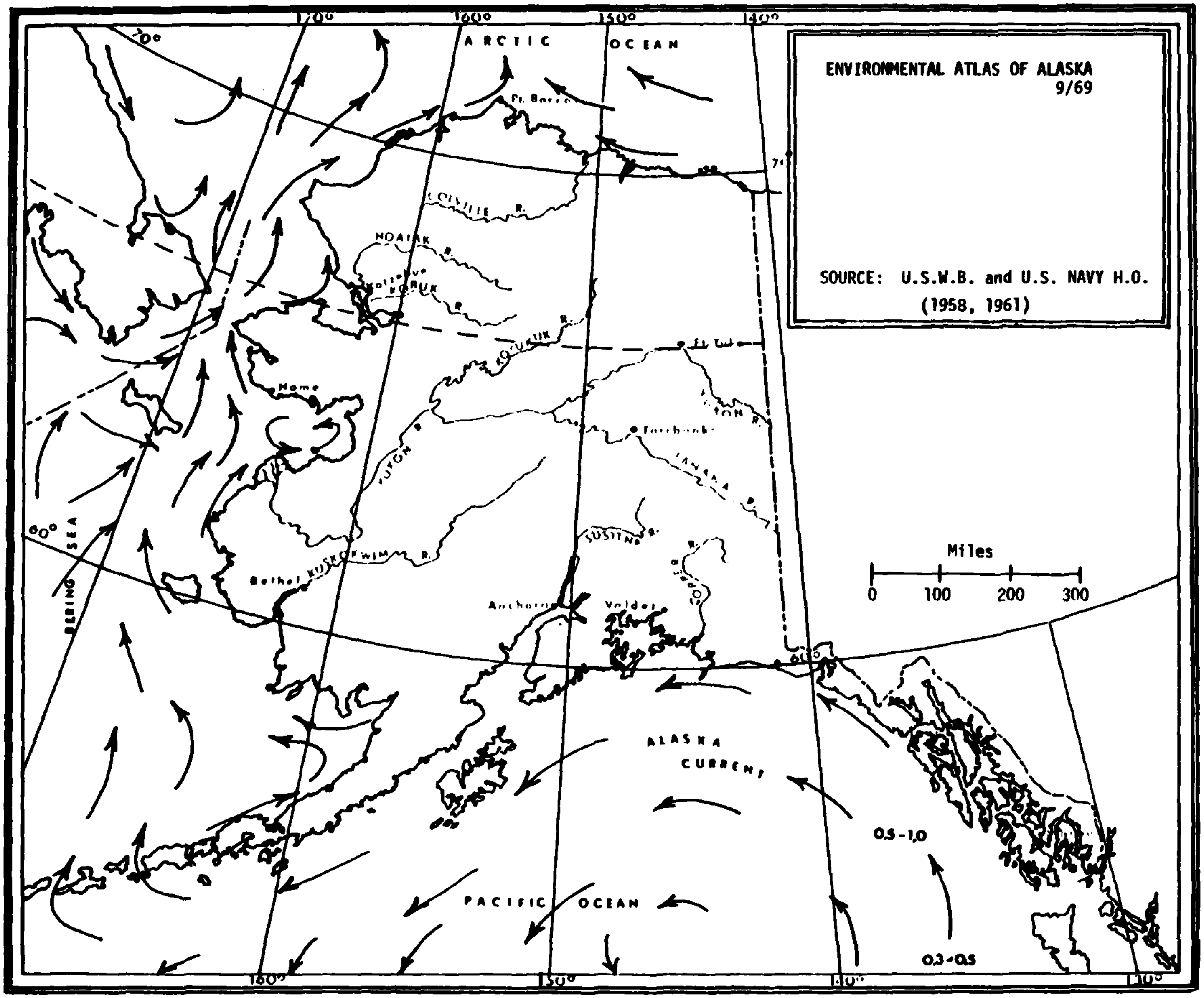


Figure 36. Summer currents of Alaskan coastal waters (knots)(from Beaufort Sea ref. 24).

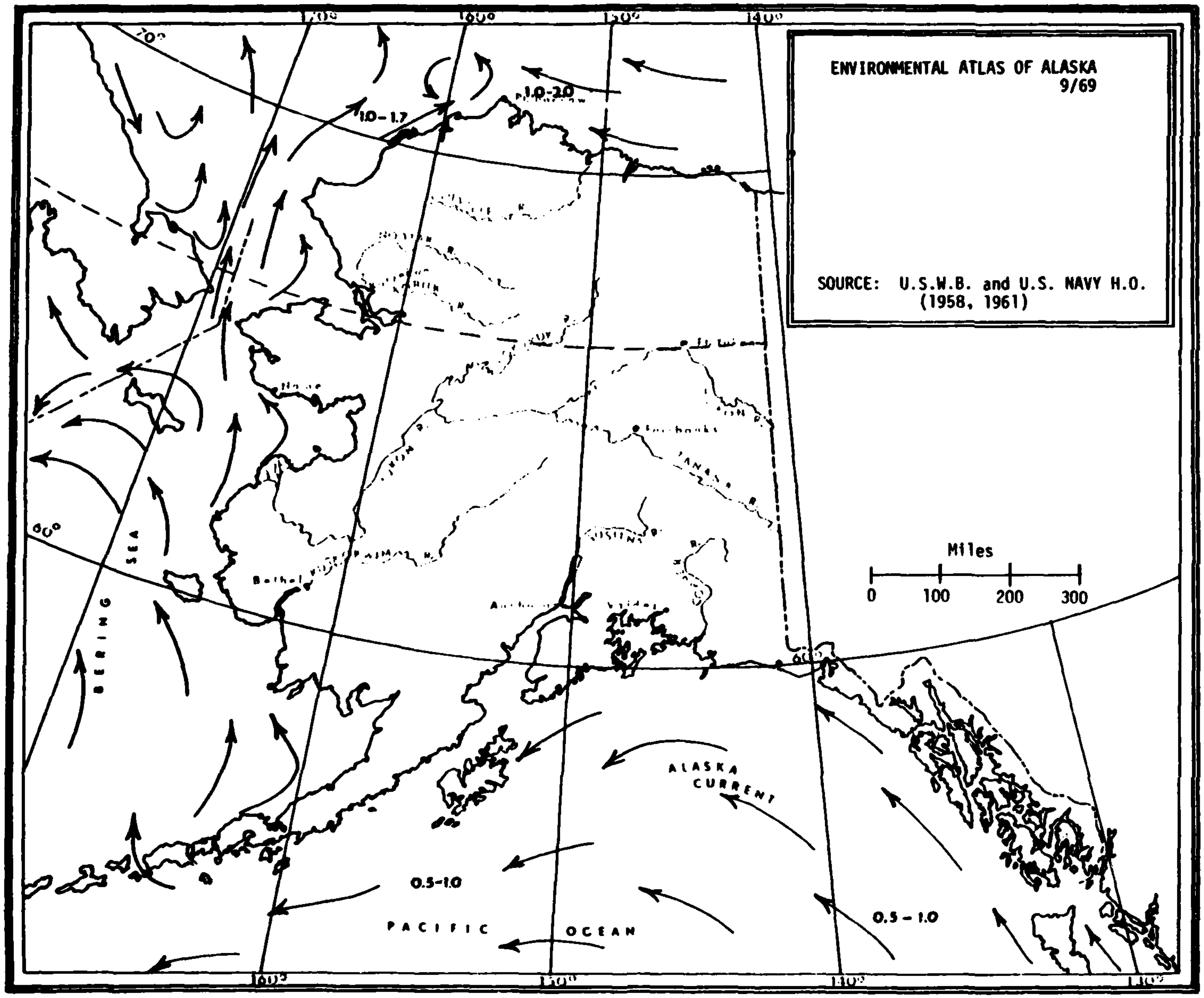


Figure 37. Winter currents of Alaskan coastal waters (knots)(from Beaufort Sea ref. 24).

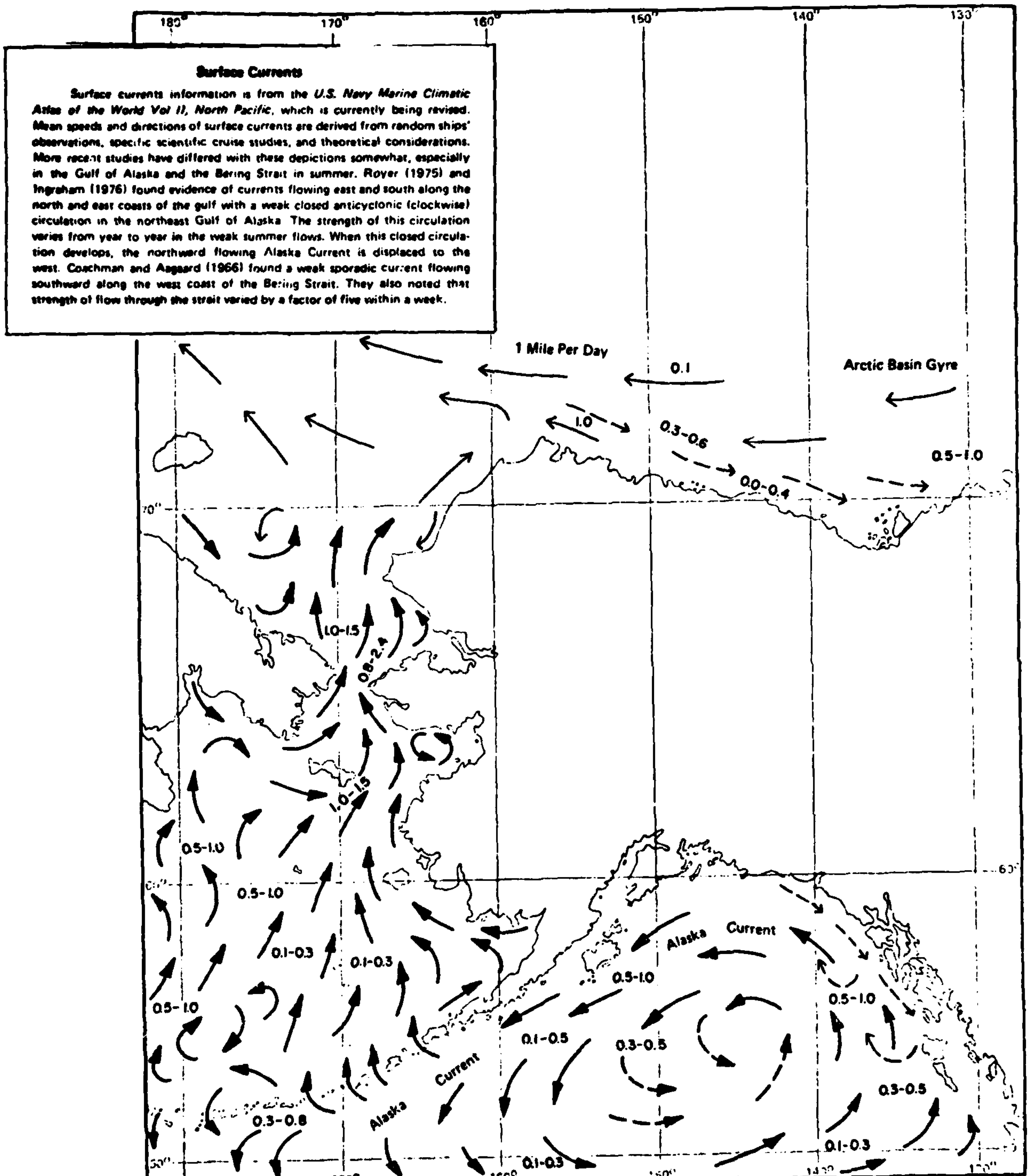
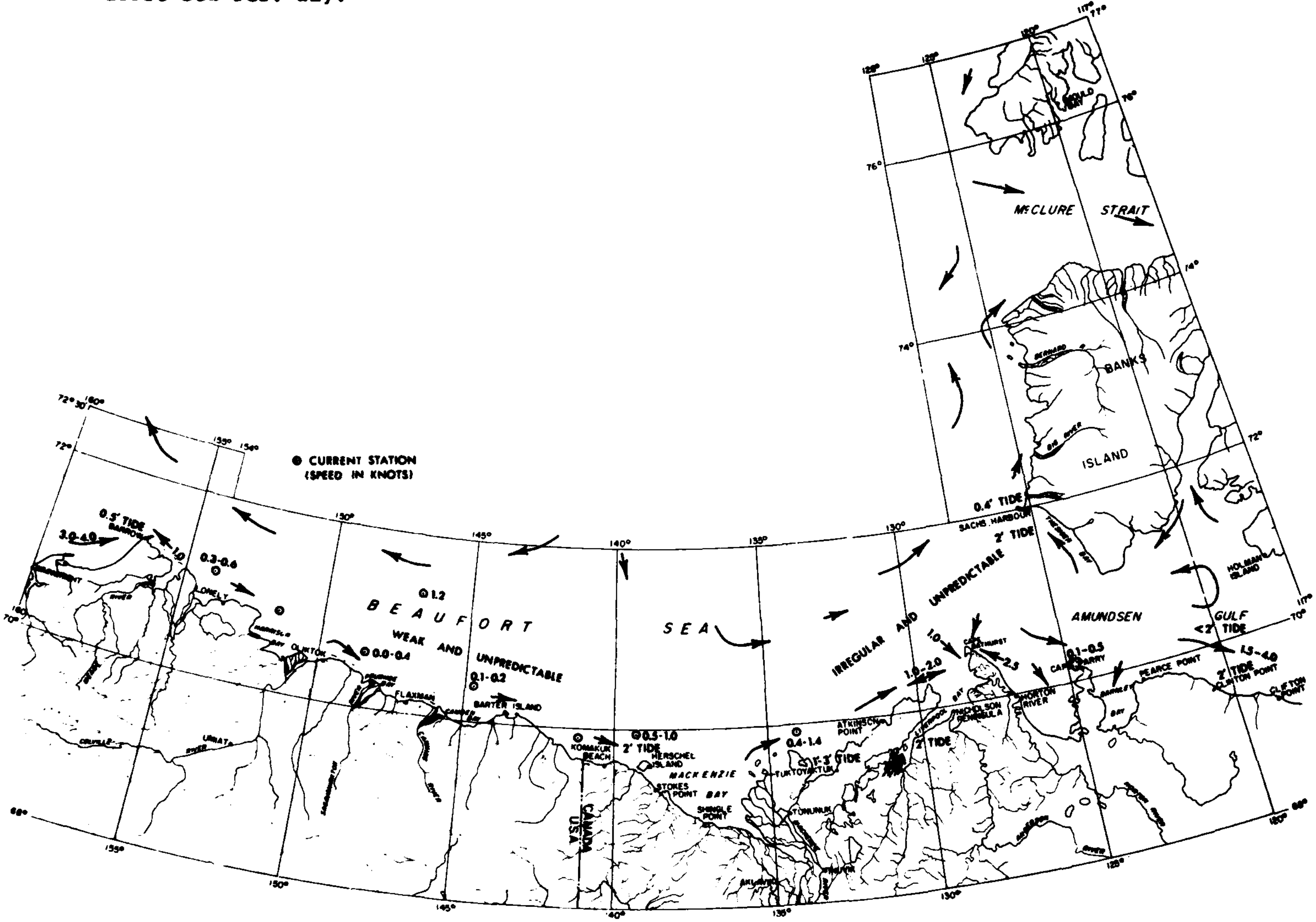


Figure 38. Summer sea surface currents (from Beaufort Sea ref. 2).

Figure 39. Tides and currents along the Beaufort Sea (from Beaufort Sea ref. 21).



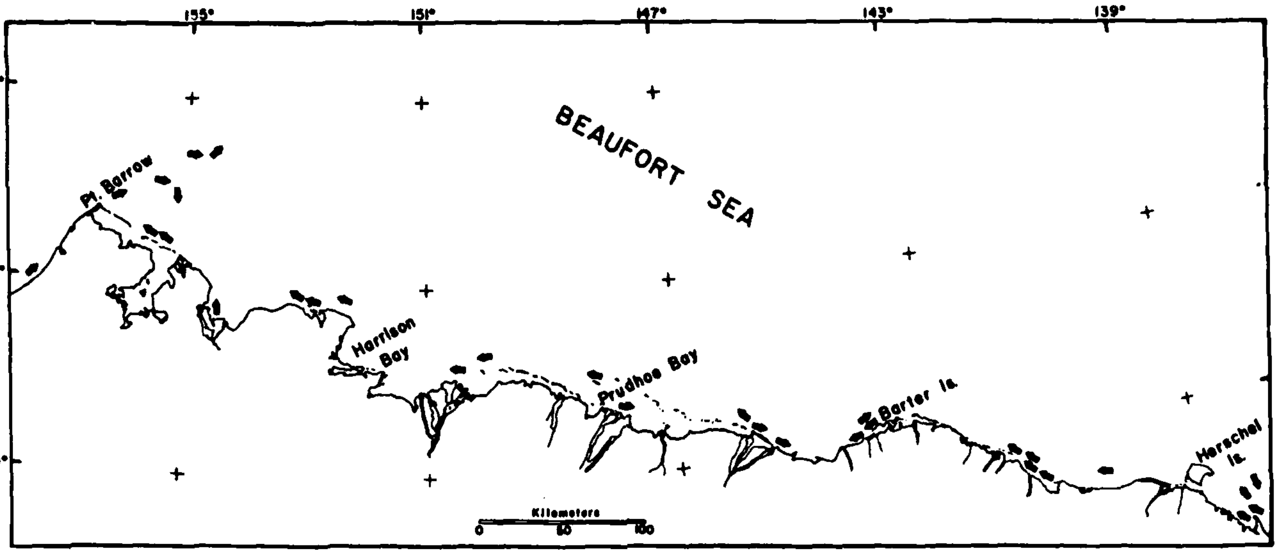


Figure 40. Coastal currents as determined using the displacement of turbid water plumes on ERTS-1 imagery during summers of 1972 and 1973 (from Beaufort Sea ref. 12).

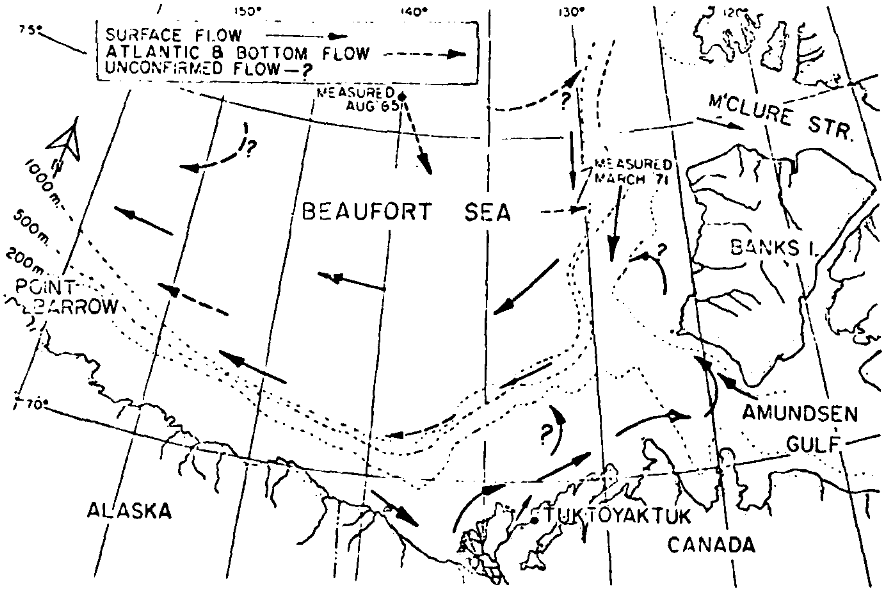


Figure 41. Horizontal distribution of surface and subsurface water movements (from Beaufort Sea ref. 11).

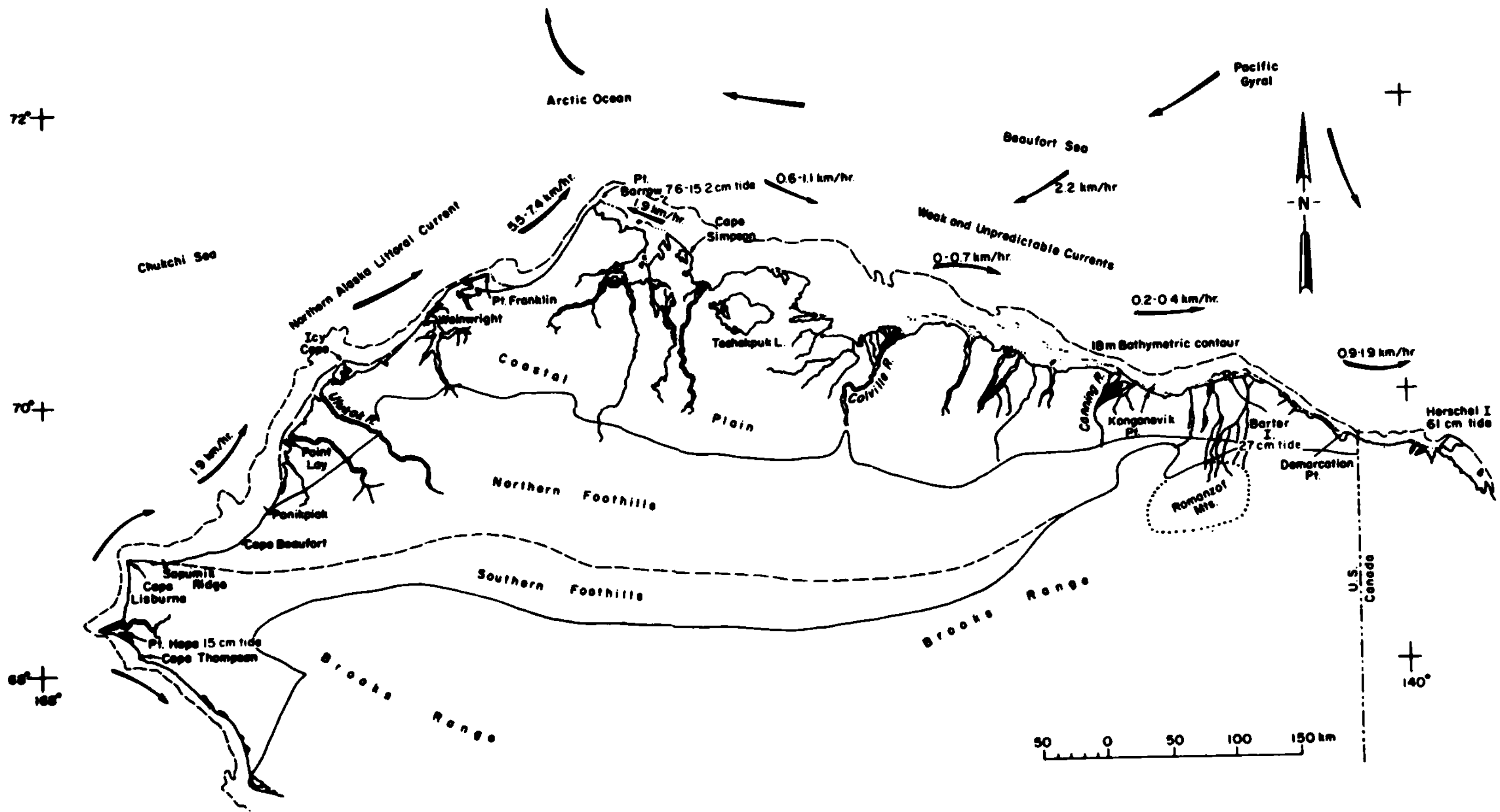


Figure 42. Currents and tides along the coast of northern Alaska (from Beaufort Sea ref. 8).

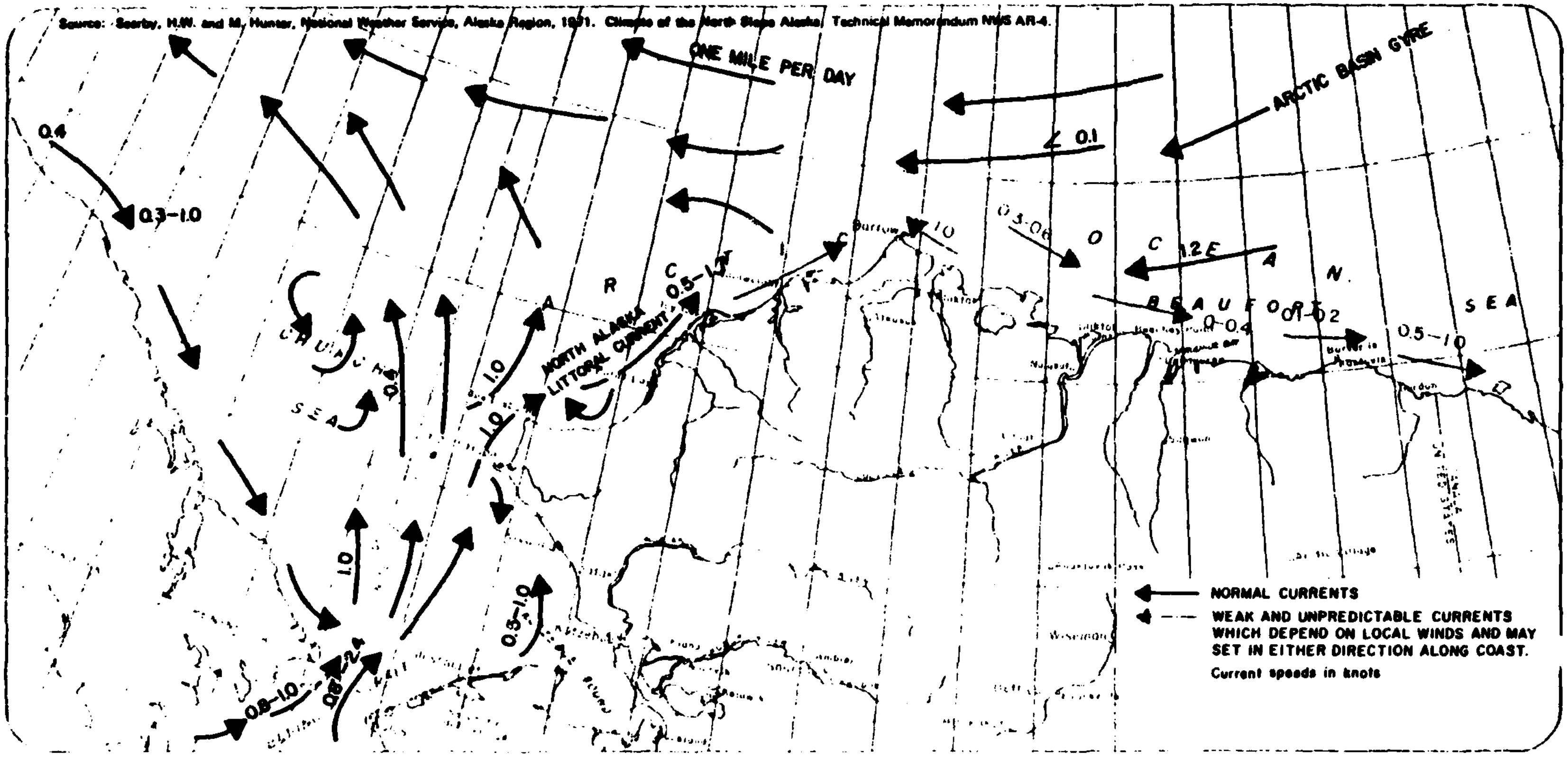


Figure 43. Currents of the Beaufort and Chukchi Seas (from Beaufort Sea ref. 1).

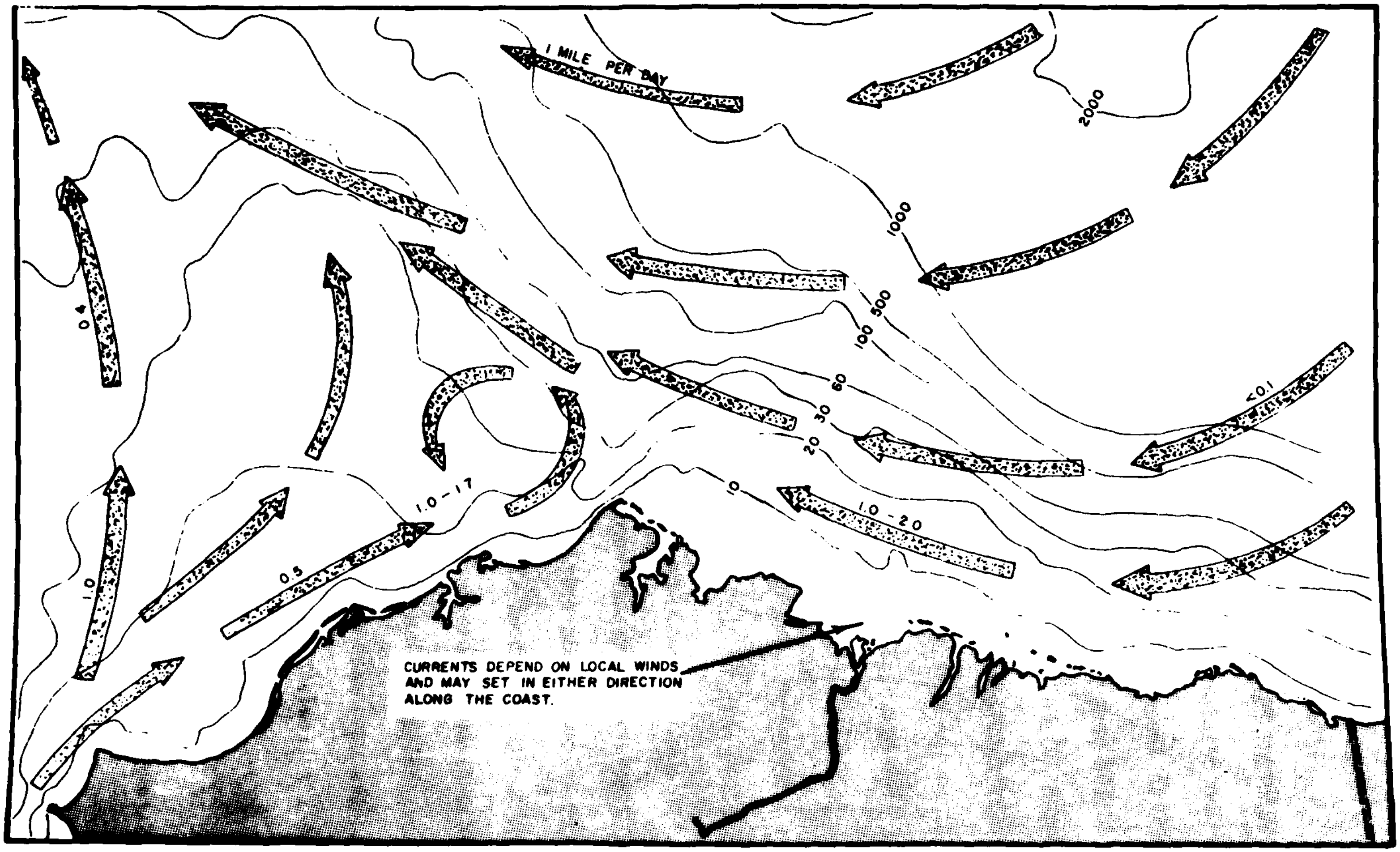


Figure 44. Generalized surface circulation (knots); depths in fathoms (from Searby and Hunter 1971) (from Beaufort Sea ref. 20).

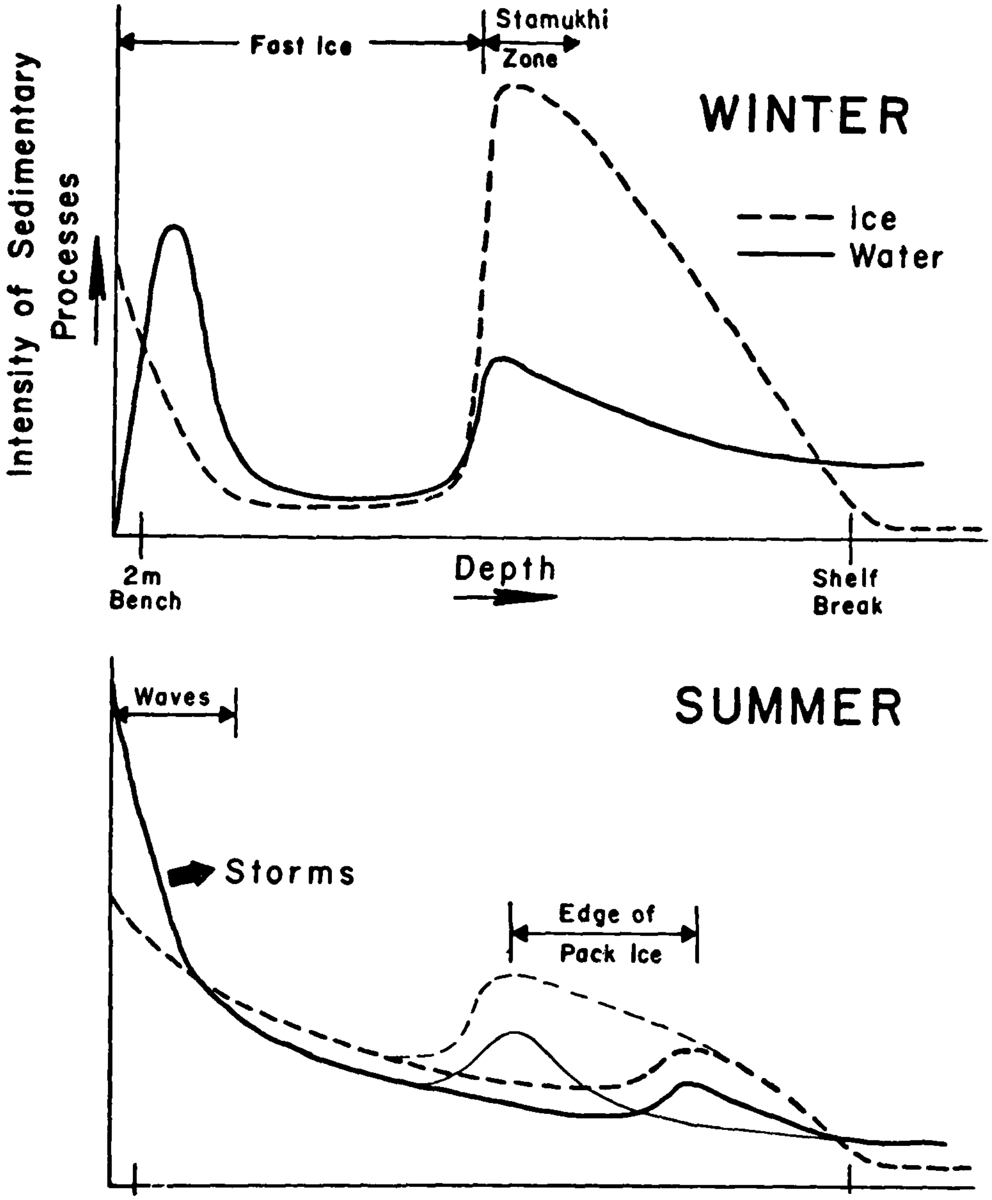


Figure 45. Relative internsities of waves, currents, ice-induced sedimentary processes during summer and winter in the Beaufort Sea. Compiled by Barnes and Reimnitz (from Beaufort Sea ref. 17).

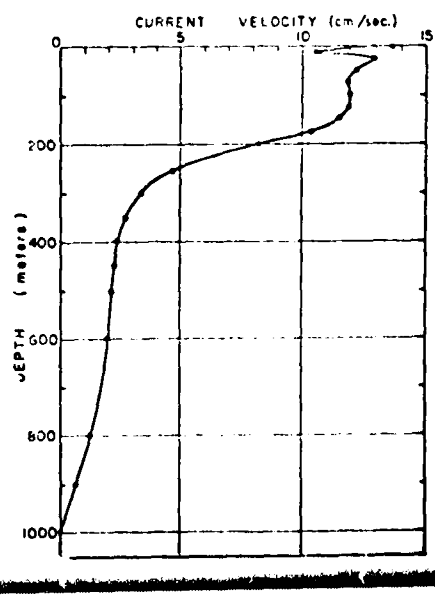


Figure 46. Vertical distribution of current component between T-3 Stations 7-8 (computed from mass field).. Kusunoki 1962) (from Beaufort Sea ref. 11).

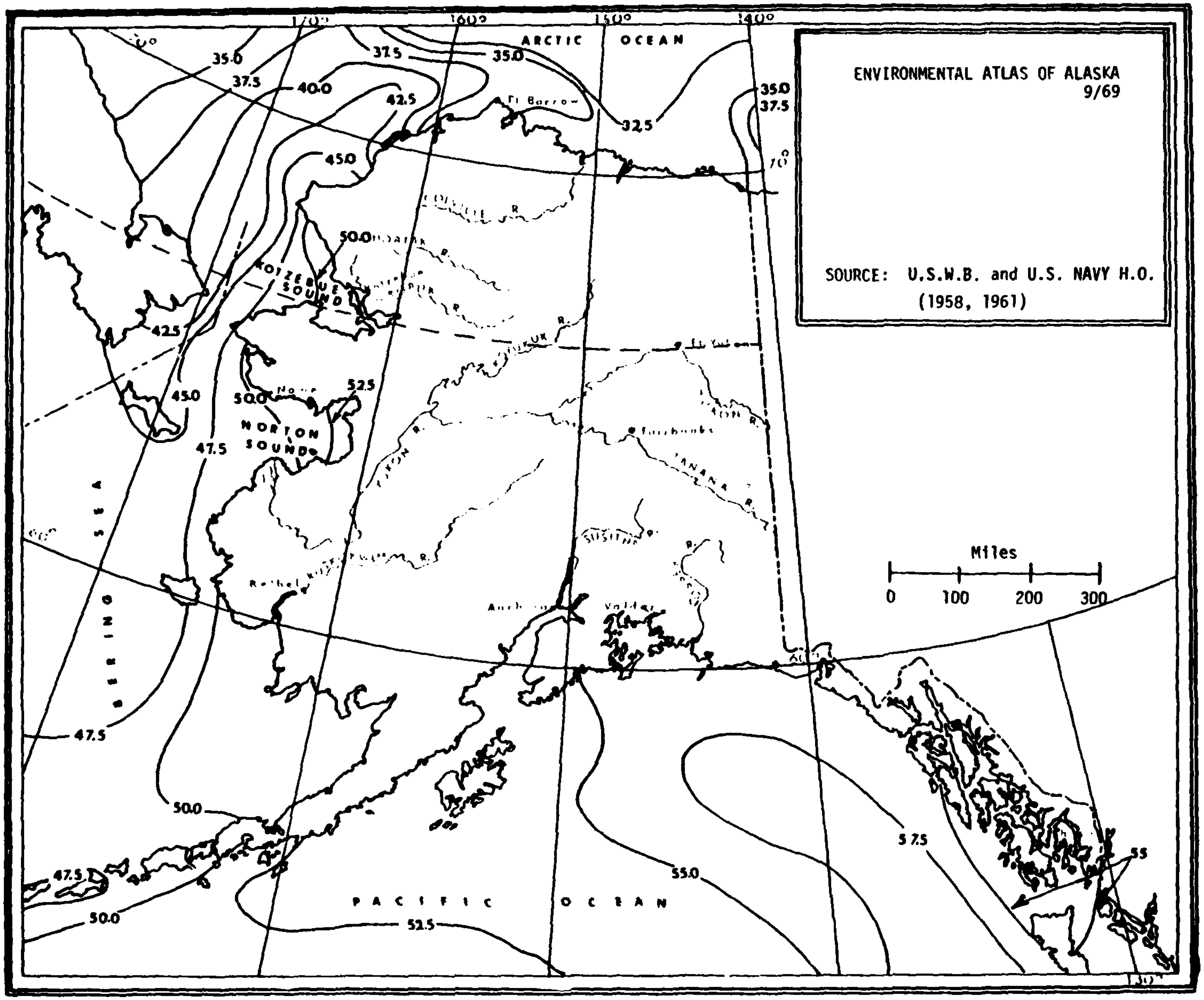


Figure 47. Summer sea temperatures off Alaska, ^{o}F (from Beaufort Sea ref. 24).

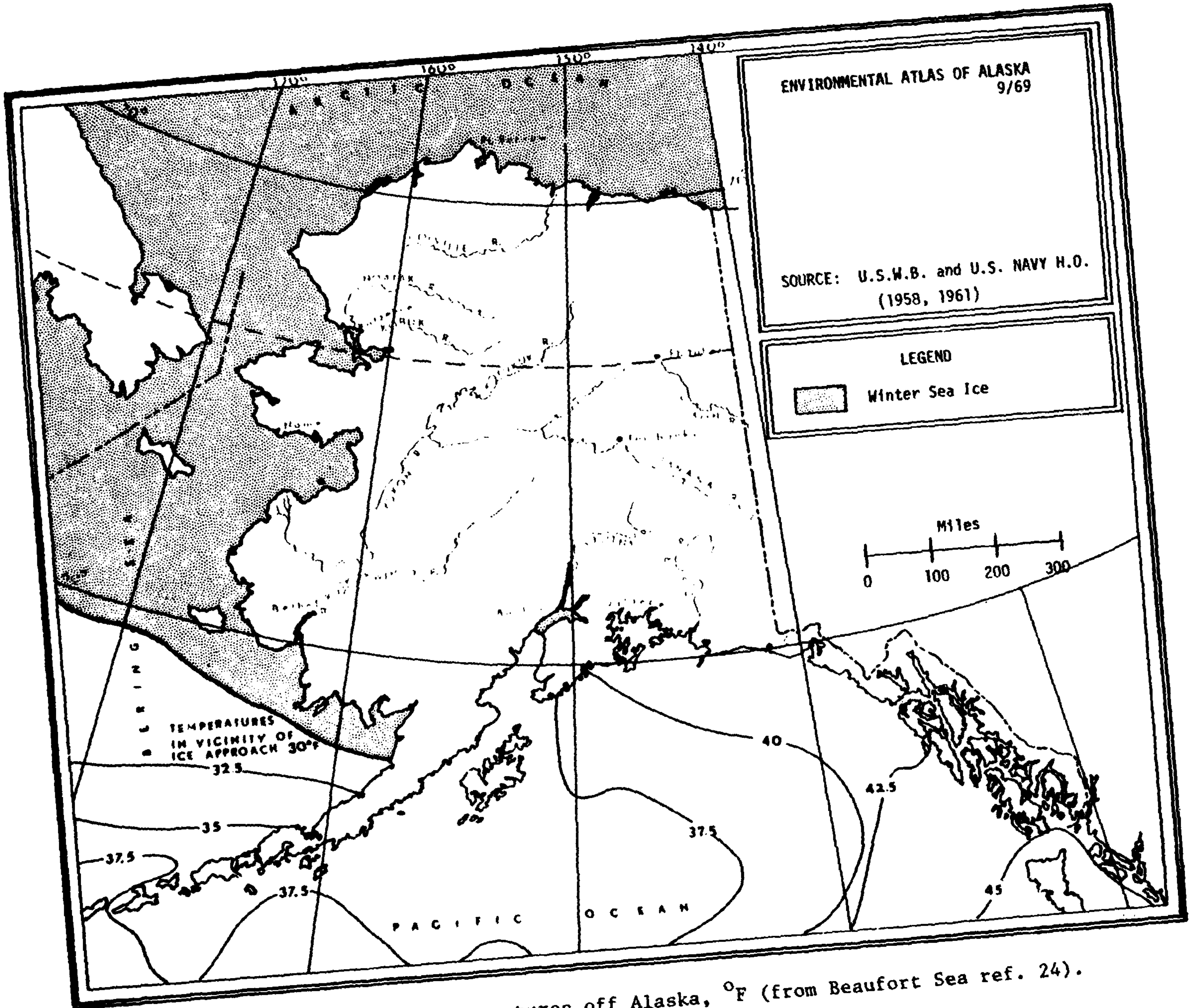


Figure 48. Winter sea temperatures off Alaska, ^{o}F (from Beaufort Sea ref. 24).

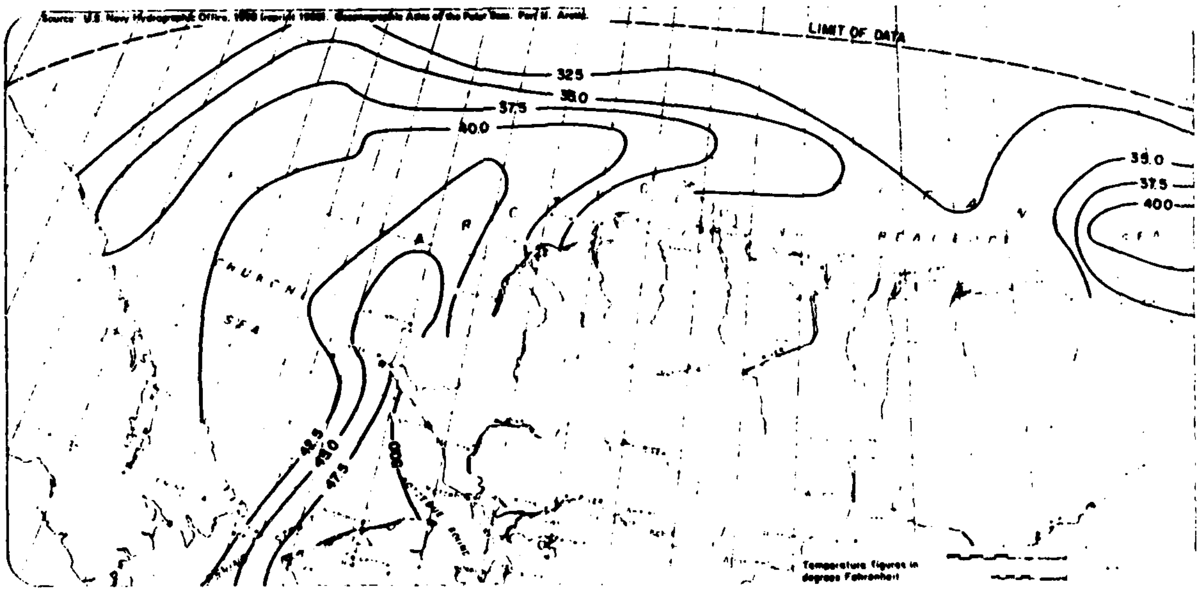


Figure 49. Average surface temperatures for August (from Beaufort Sea ref. 1).

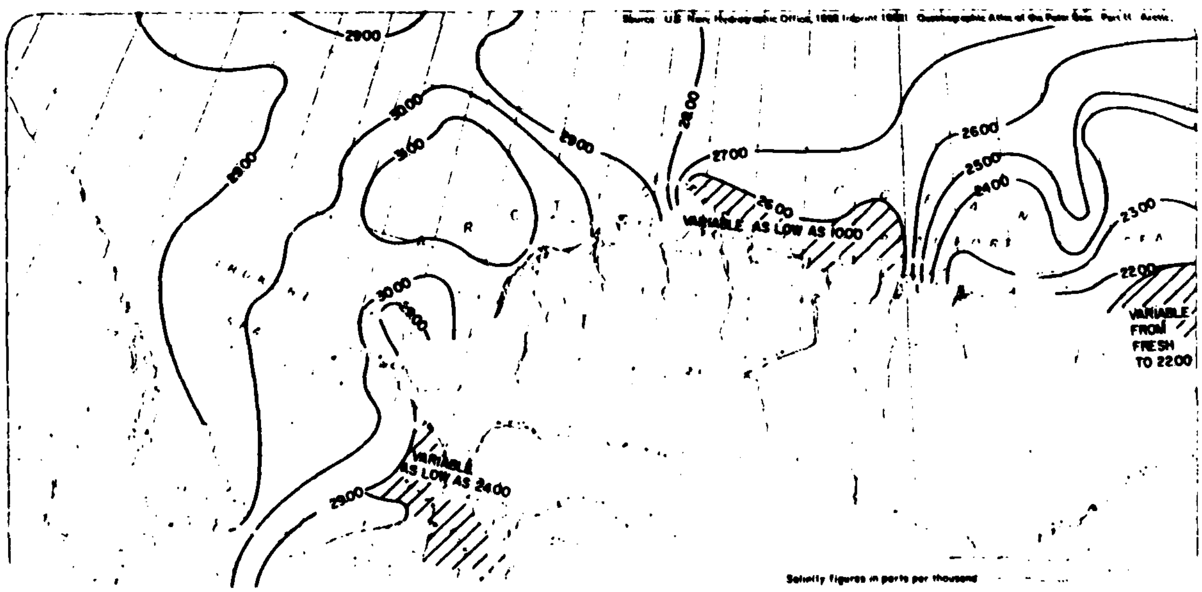


Figure 50. Average surface salinity in summer (from Beaufort Sea ref. 1).

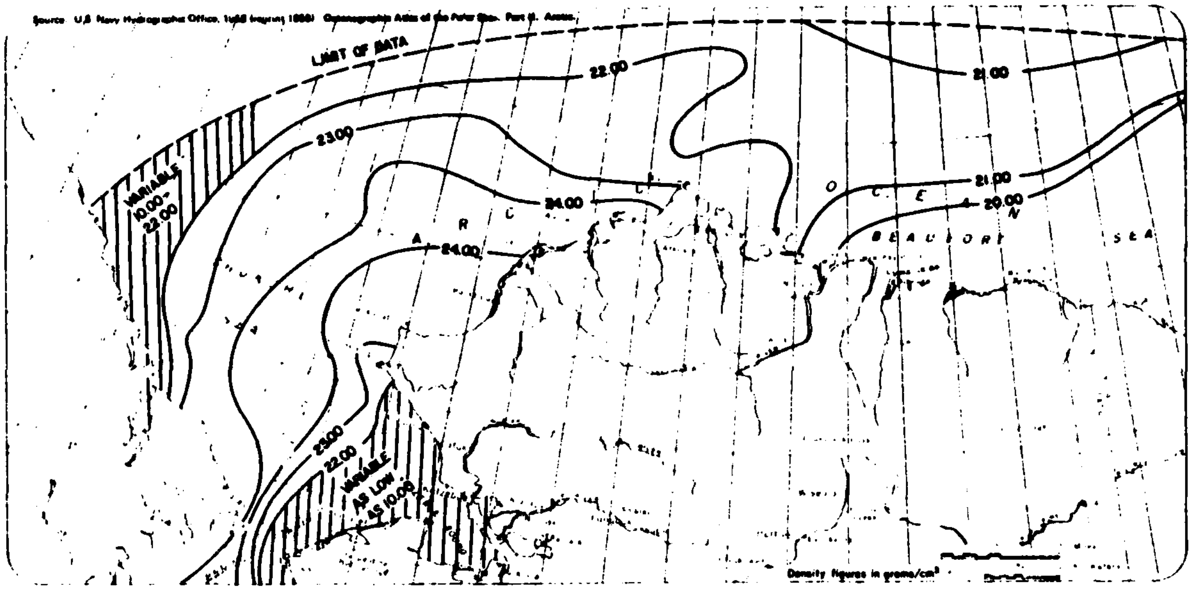


Figure 51. Average surface density in the Chukchi and Beaufort Seas (from Beaufort Sea ref. 1).

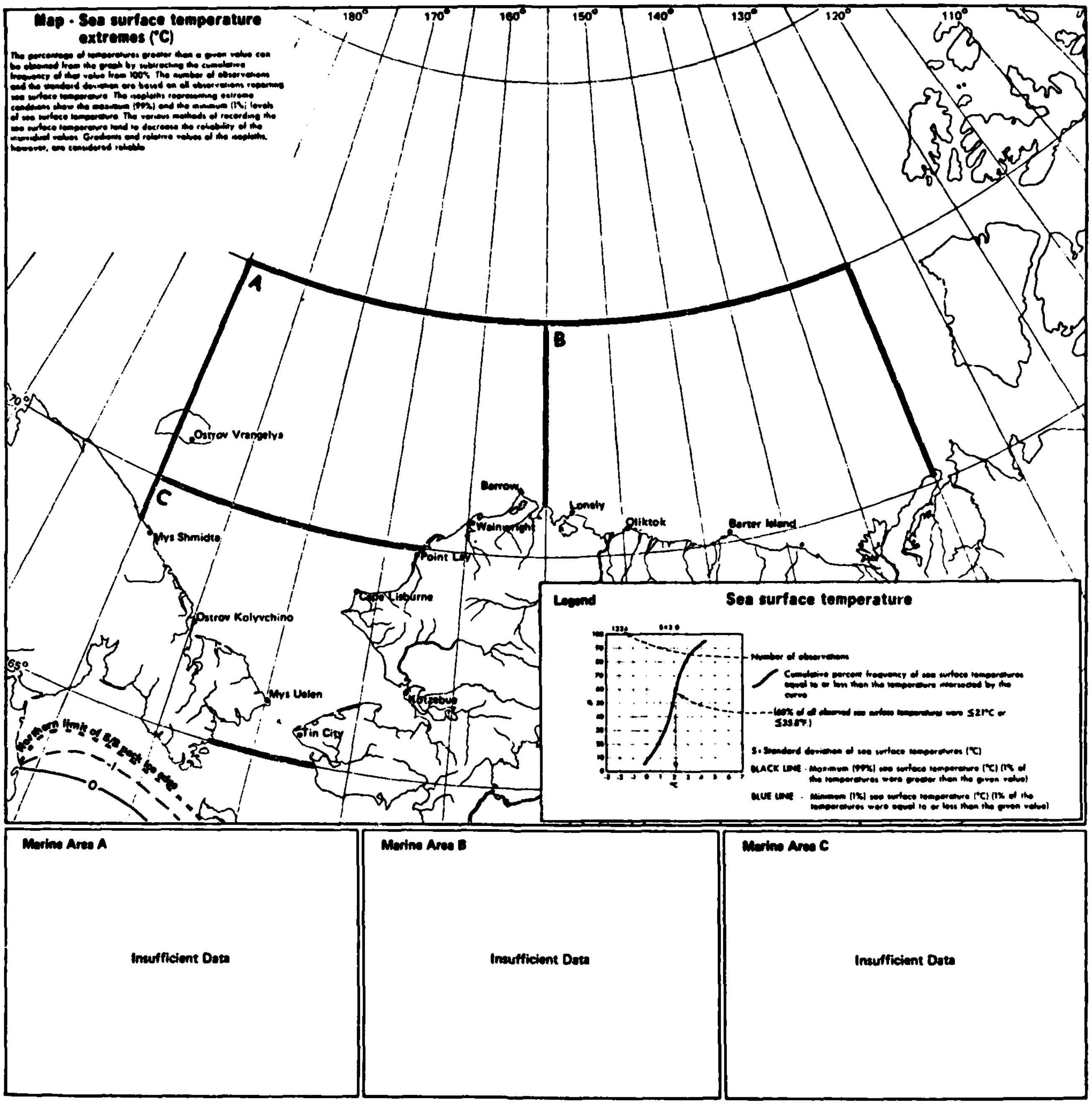


Figure 52. Sea surface temperature extremes, January (from Beaufort Sea ref. 2).

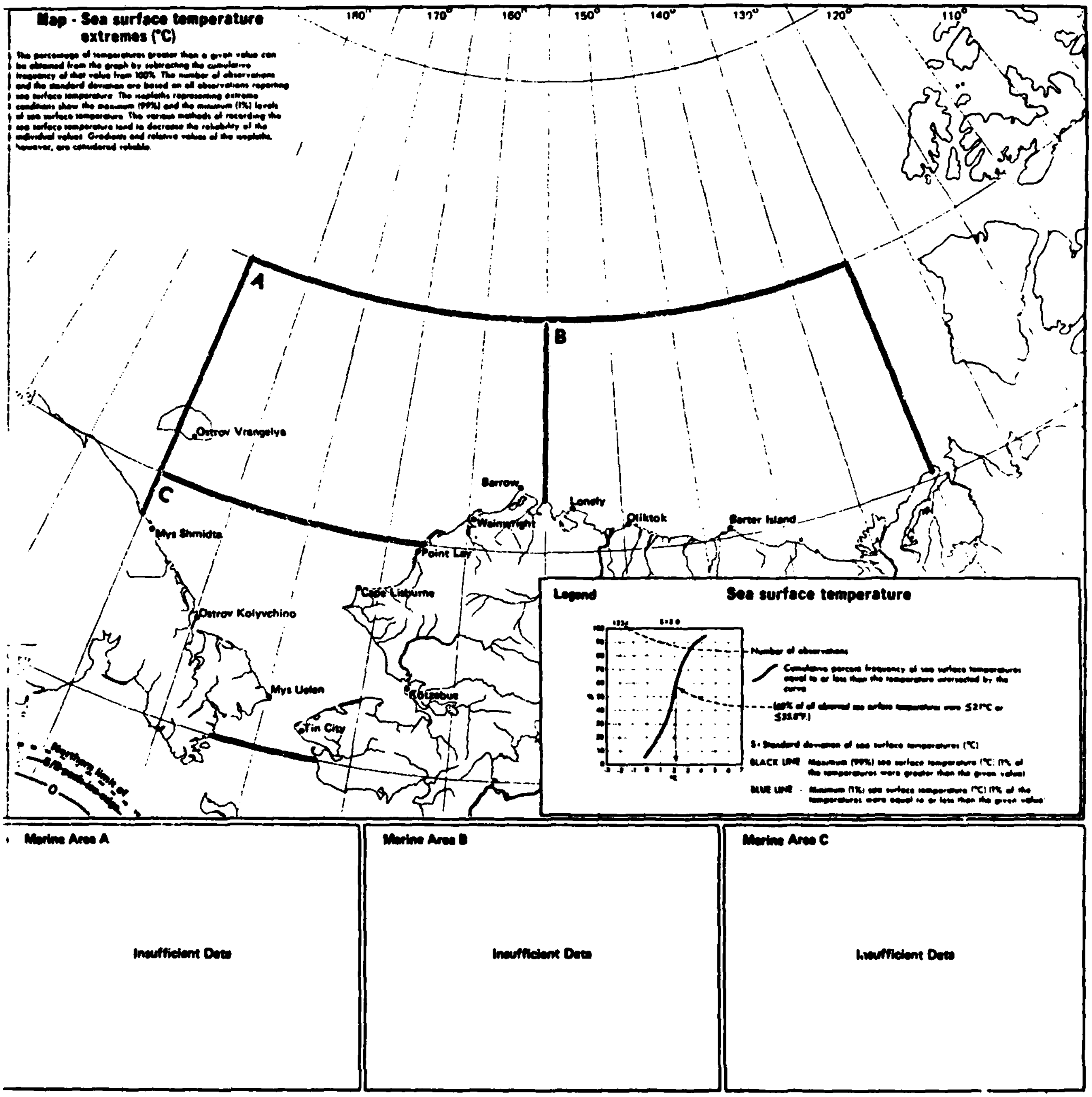


Figure 53. Sea surface temperature extremes, February (from Beaufort Sea ref. 2).

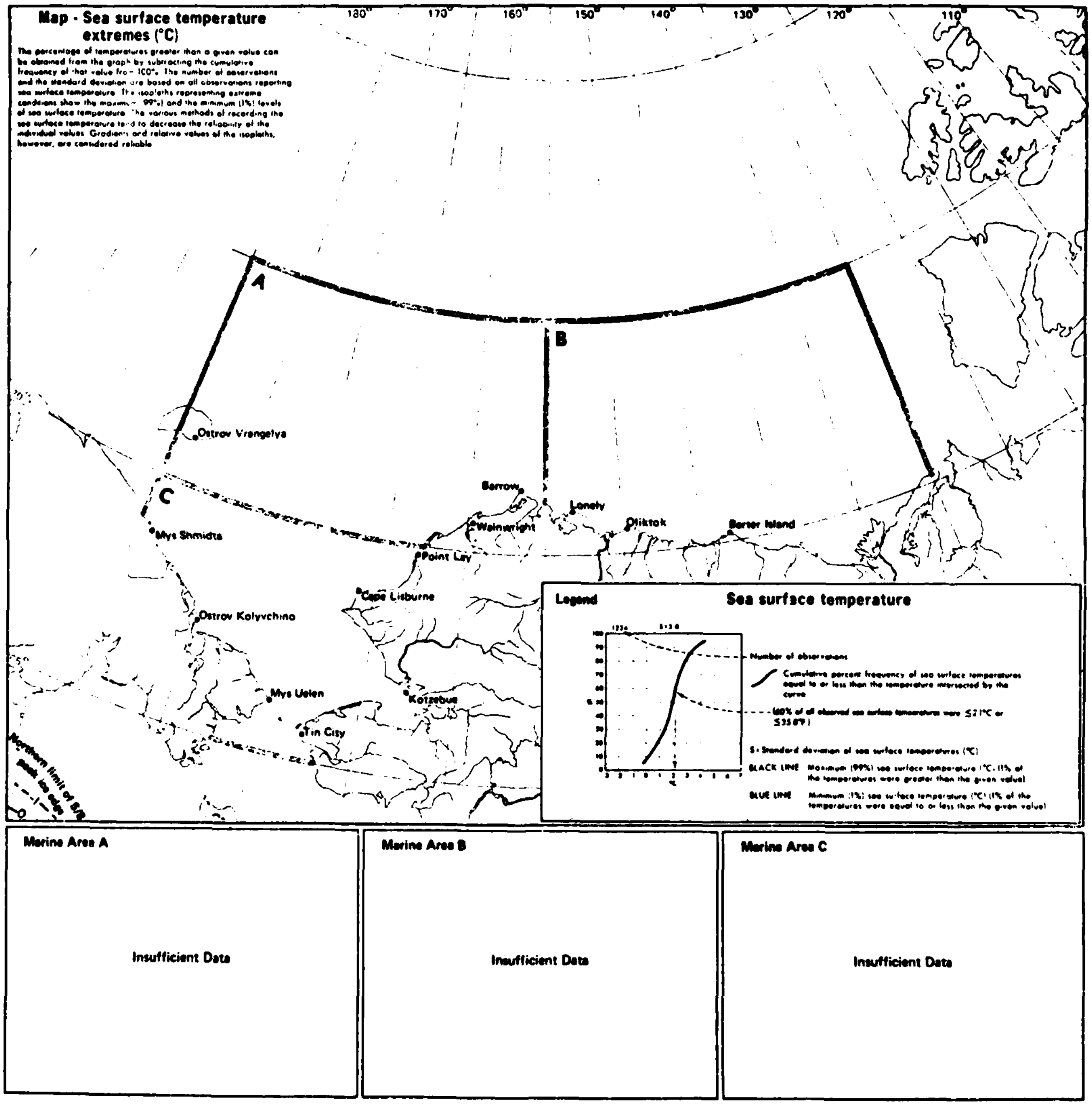


Figure 54. Sea surface temperature extremes, March (from Beaufort Sea ref. 2).

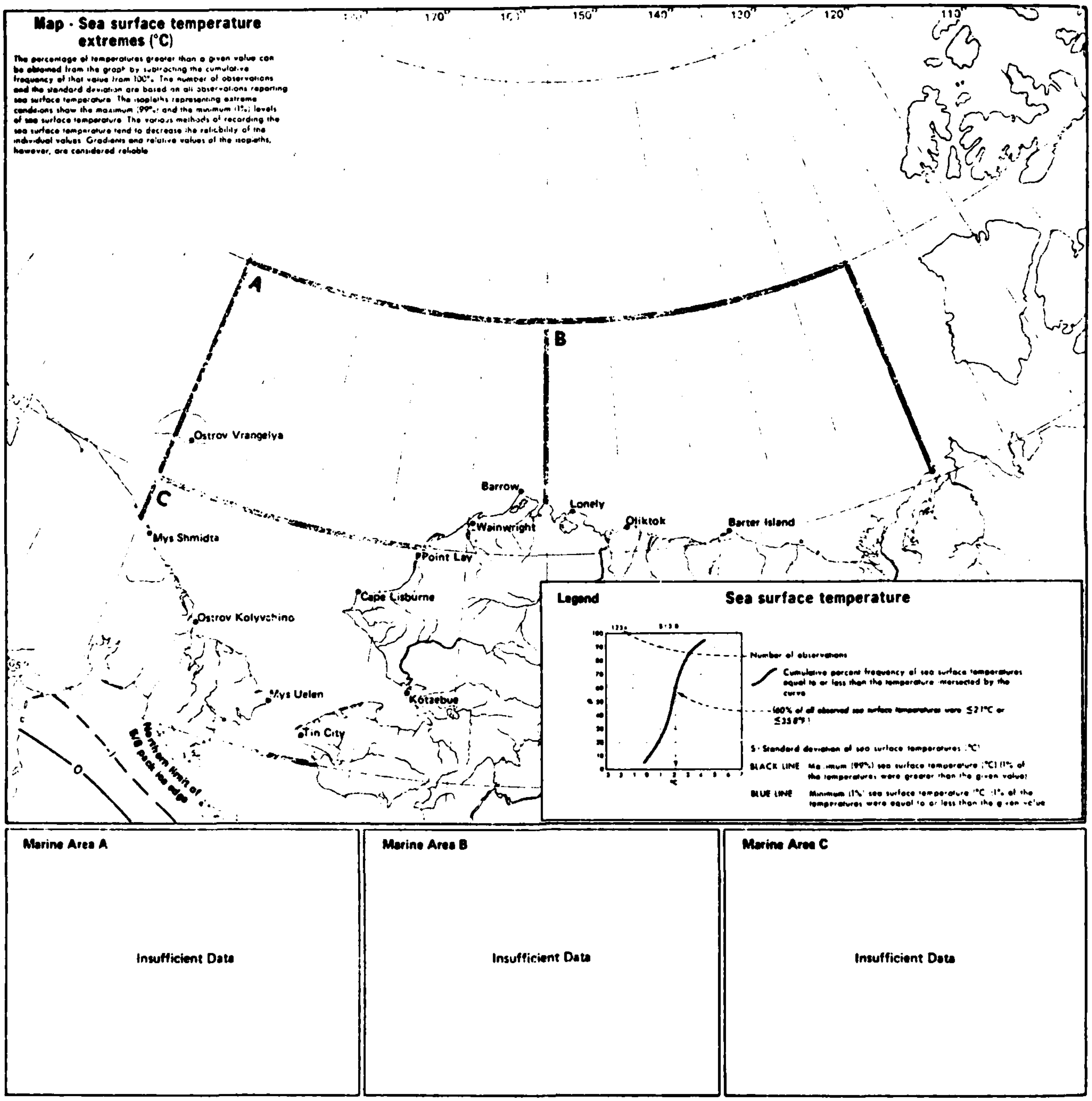


Figure 55. Sea surface temperature extremes, April (from Beaufort Sea ref. 2).

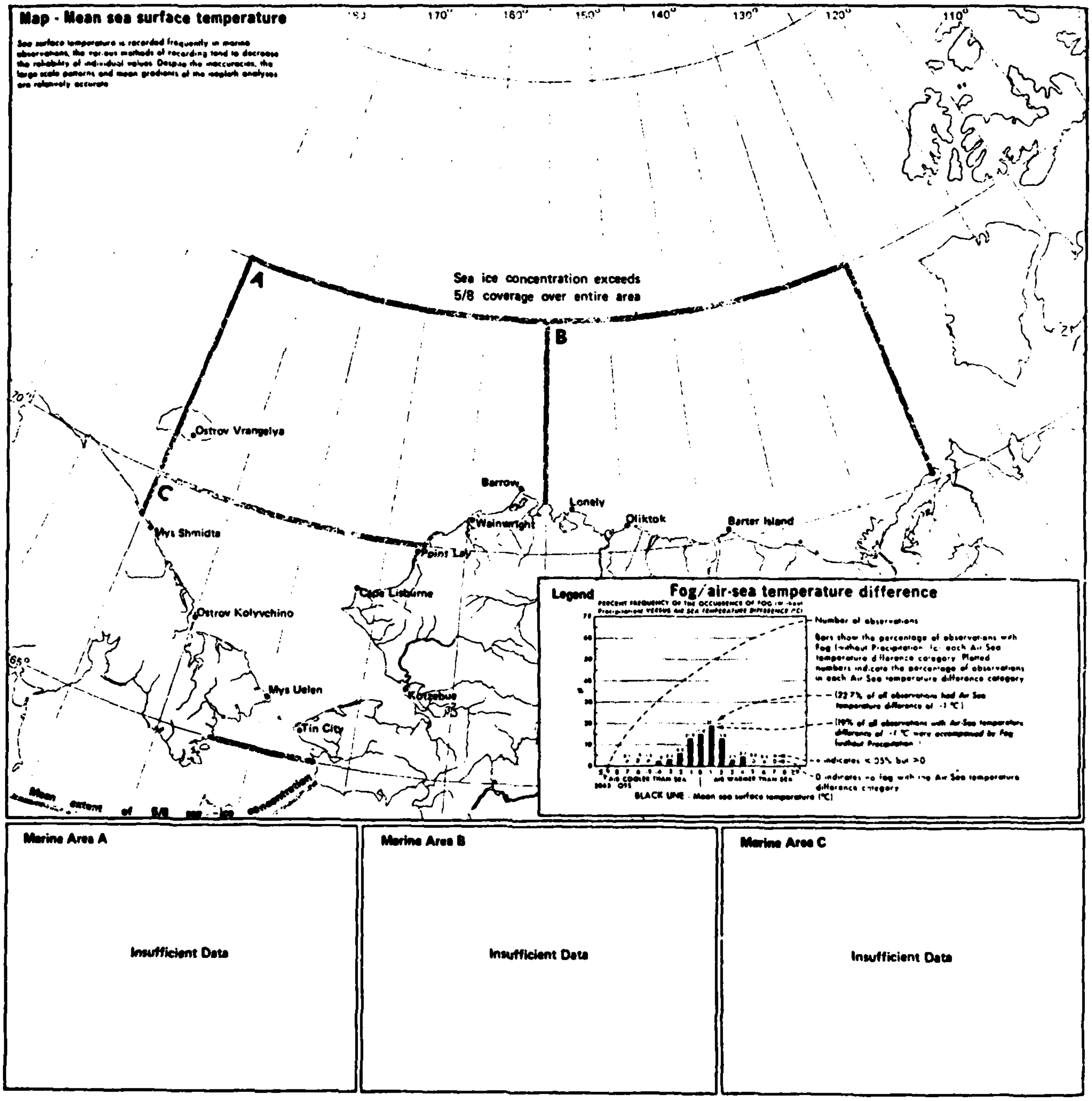


Figure 56. Fog/air-sea temperature difference, mean sea surface temperature, May (from Beaufort Sea ref. 2).

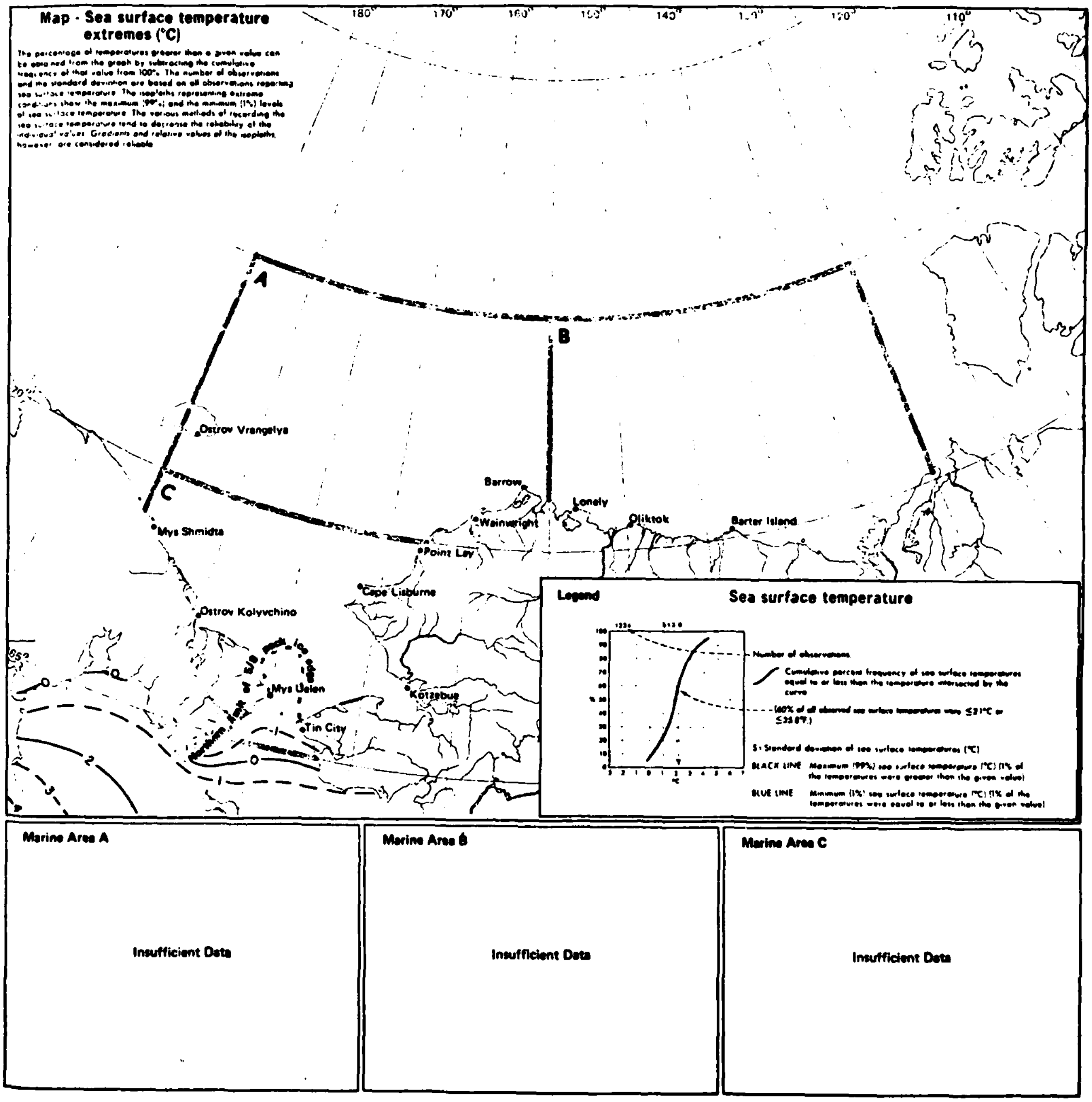


Figure 57. Sea surface temperature extremes, May (from Beaufort Sea ref. 2).

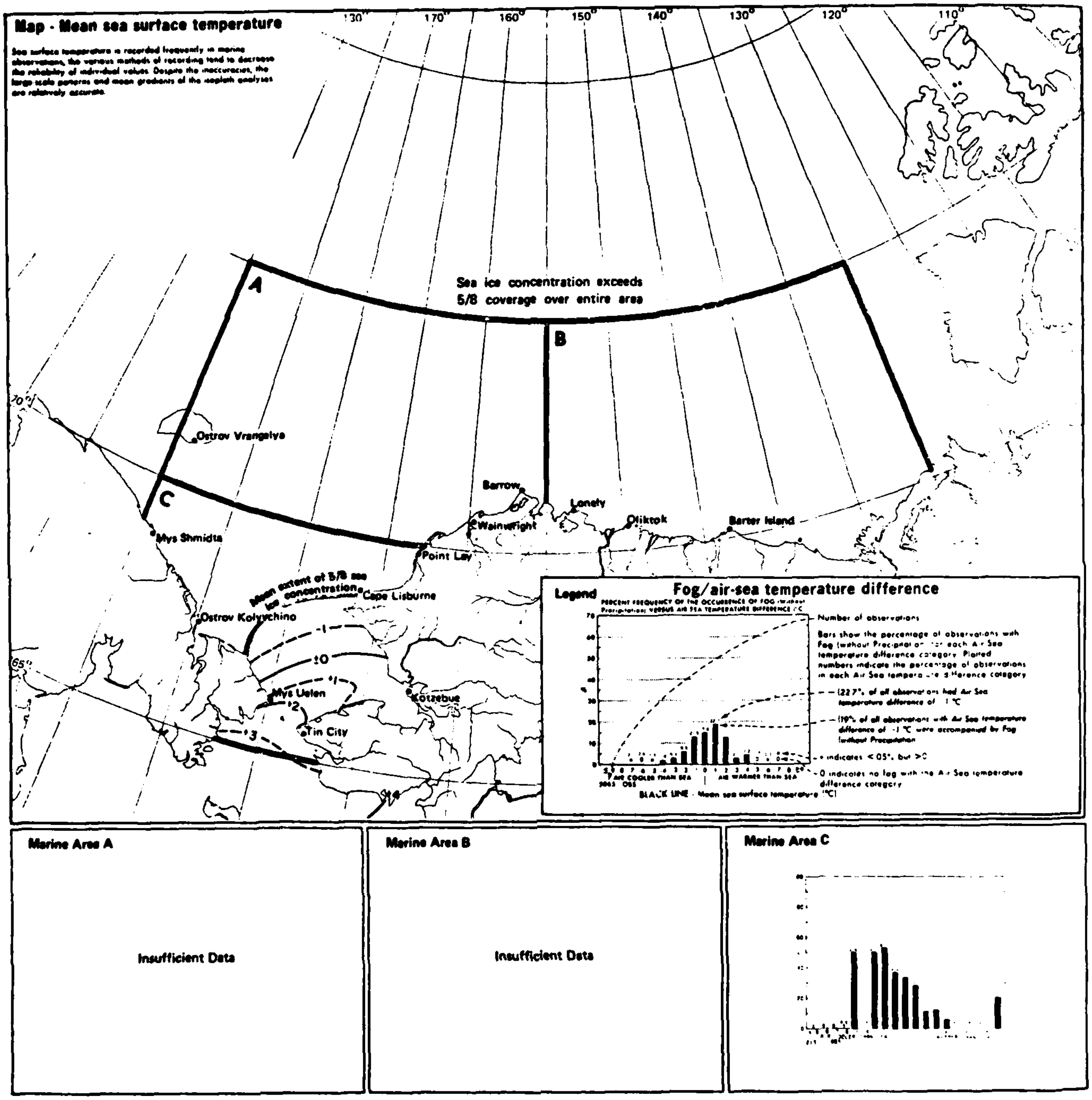


Figure 58. Fog/air-sea temperature difference, mean sea surface temperature, June (from Beaufort Sea ref. 2).

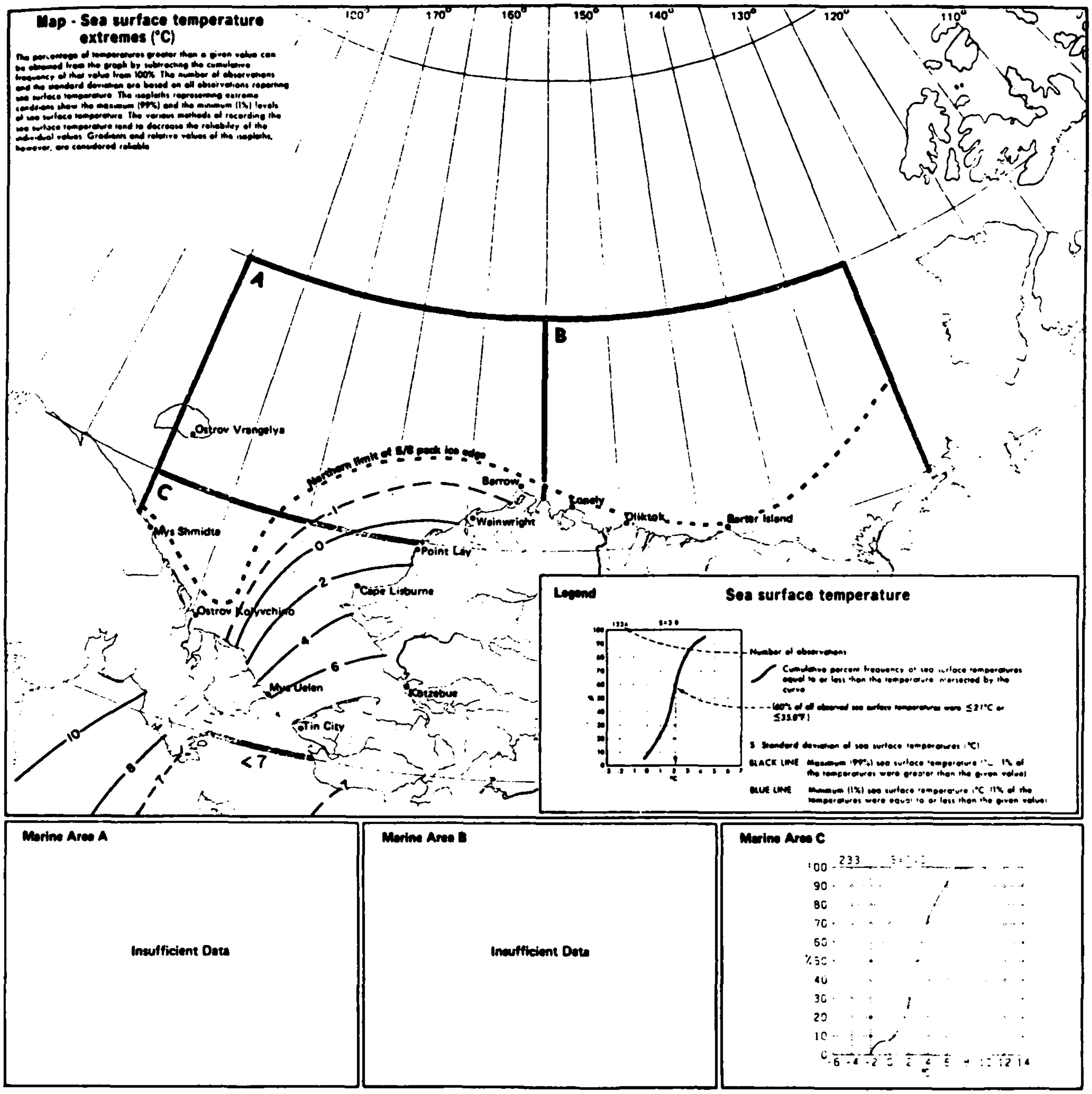


Figure 59. Sea surface temperature extremes, June (from Beaufort Sea ref. 2).

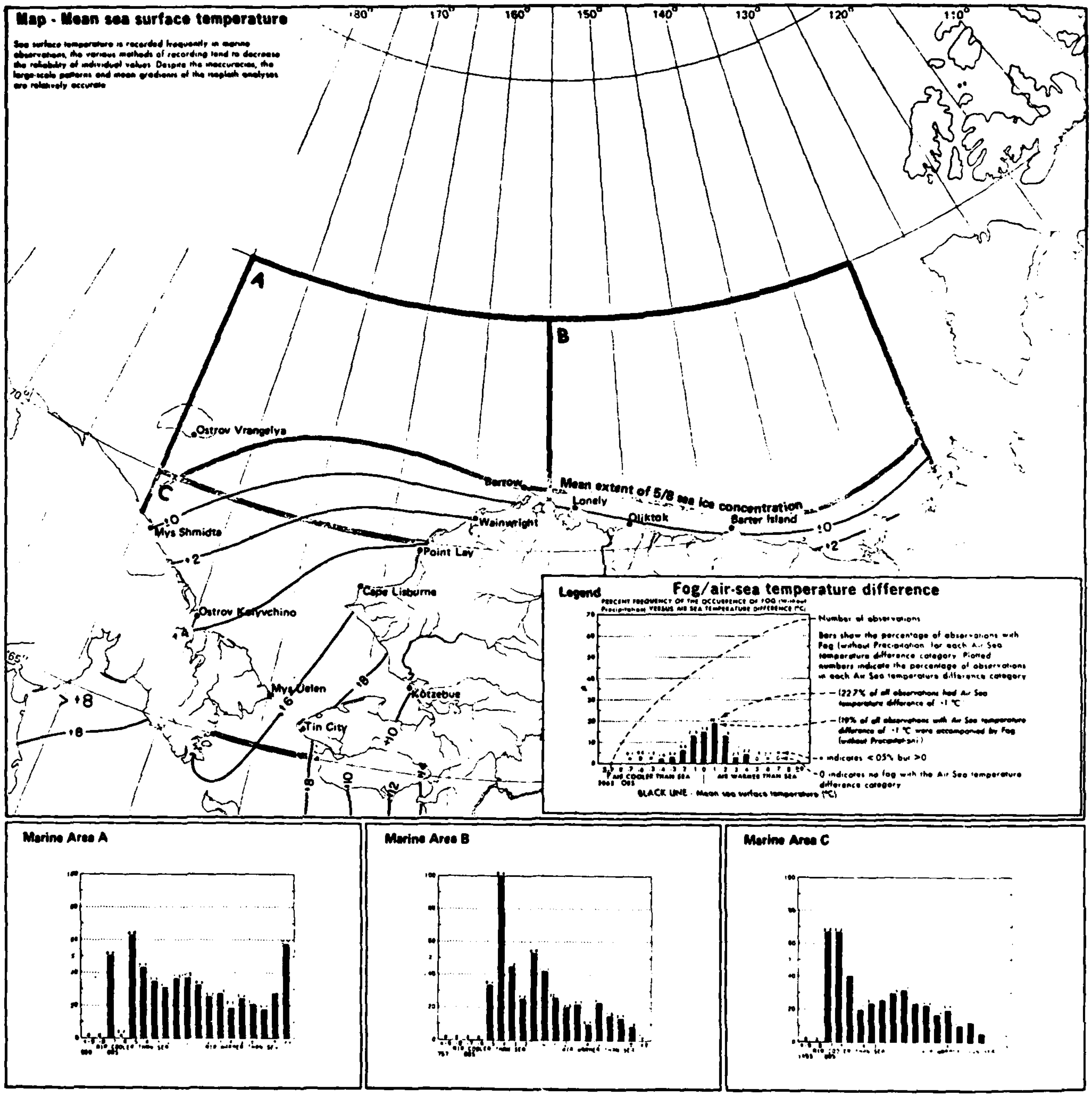


Figure 60. Fog/air-sea temperature difference, mean sea surface temperature, July (from Beaufort Sea ref. 2).

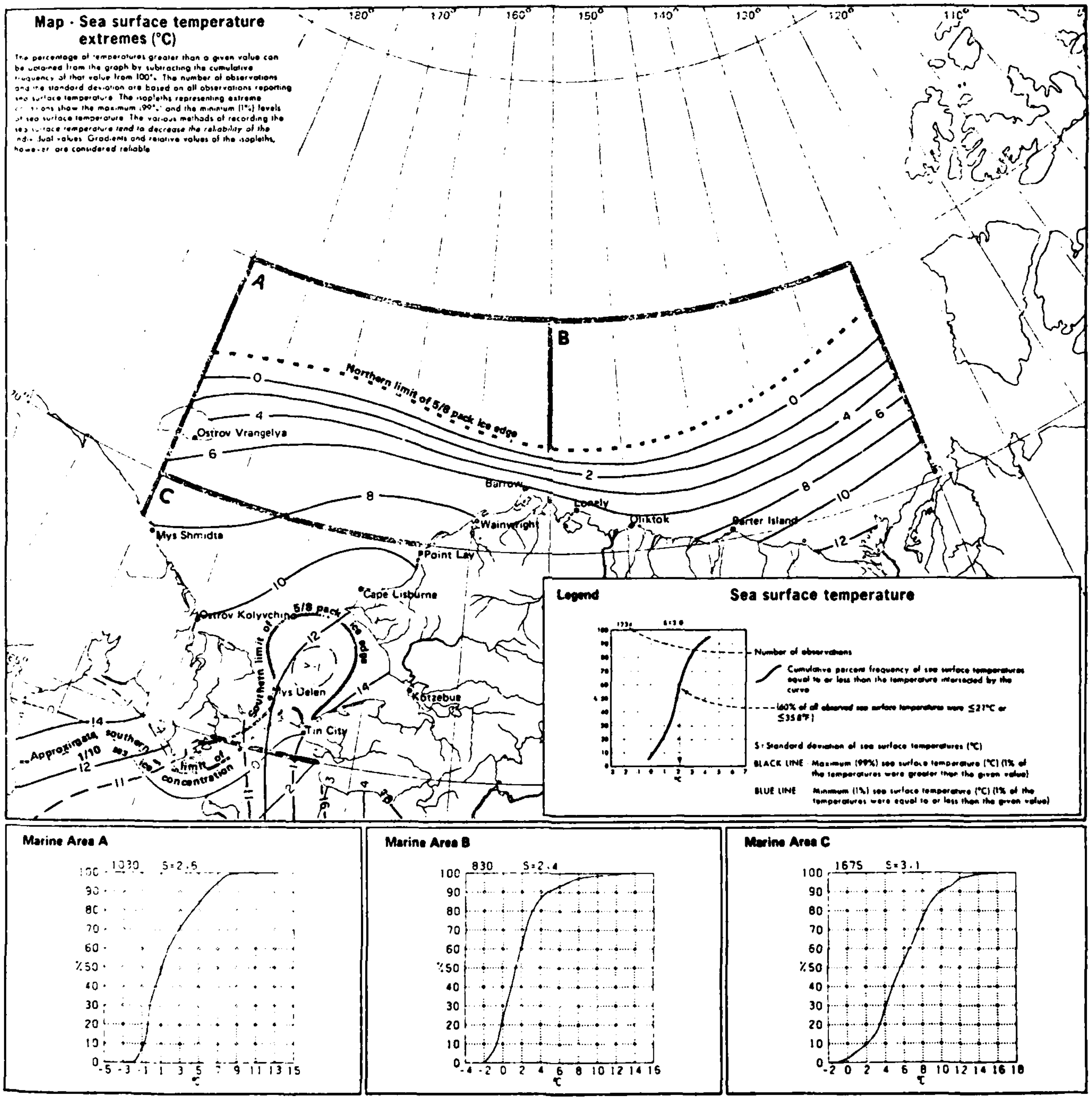


Figure 61. Sea surface temperature extremes, July (from Beaufort Sea ref. 2).

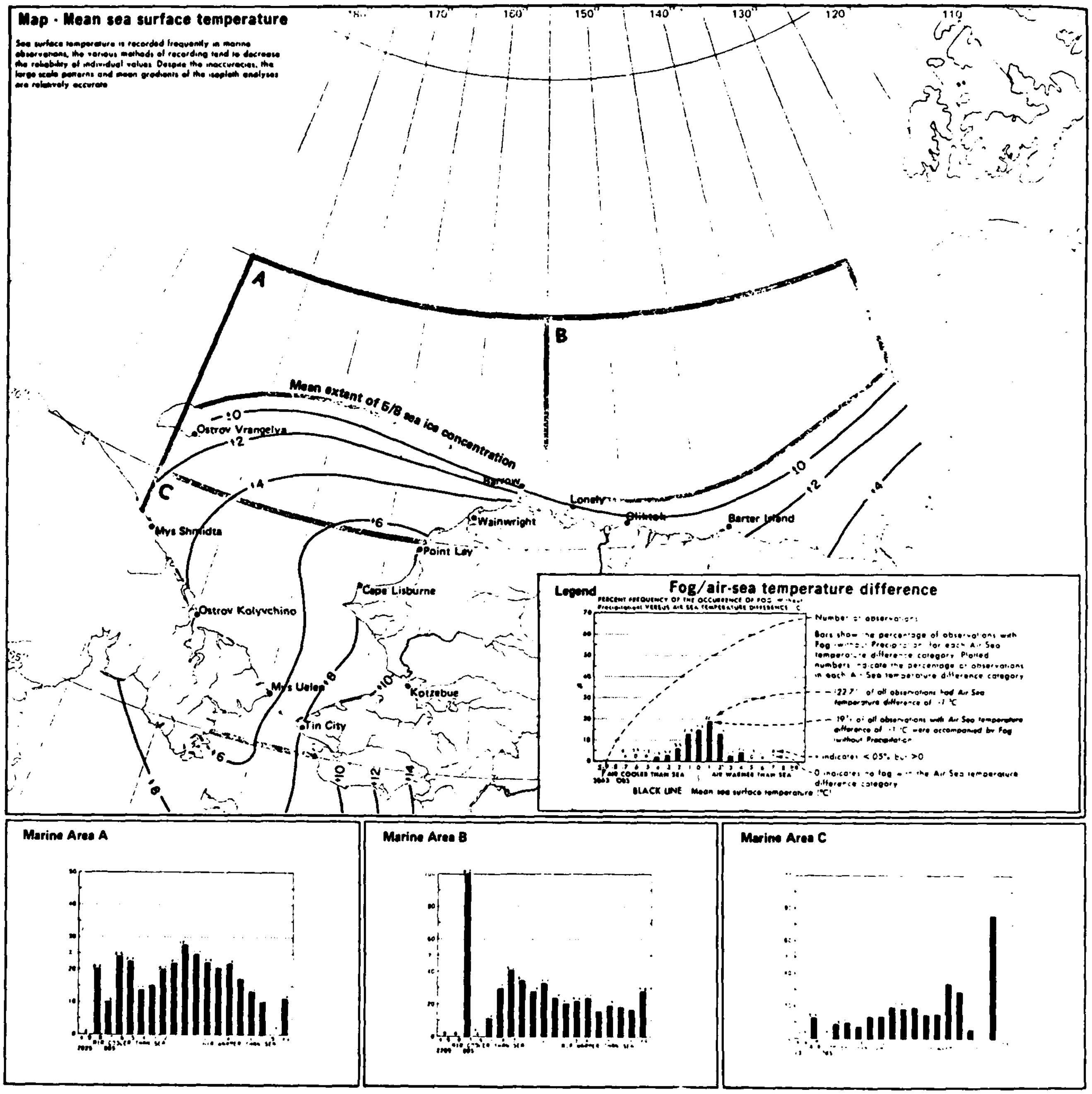


Figure 62. Fog/air-sea temperature difference, mean sea surface temperature, August (from Beaufort Sea ref. 2).

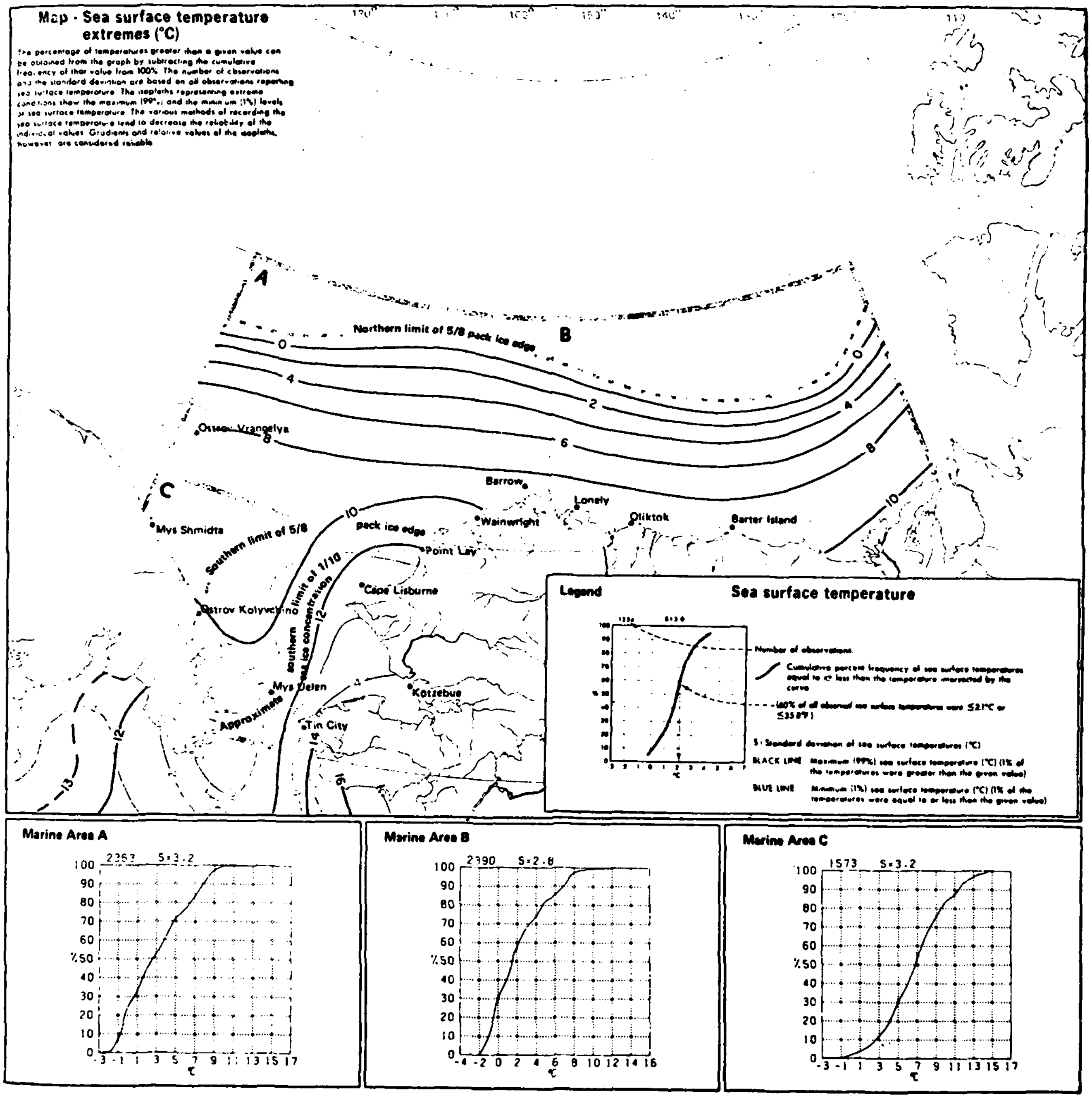


Figure 63.. Sea surface temperature extremes, August (from Beaufort Sea ref. 2).

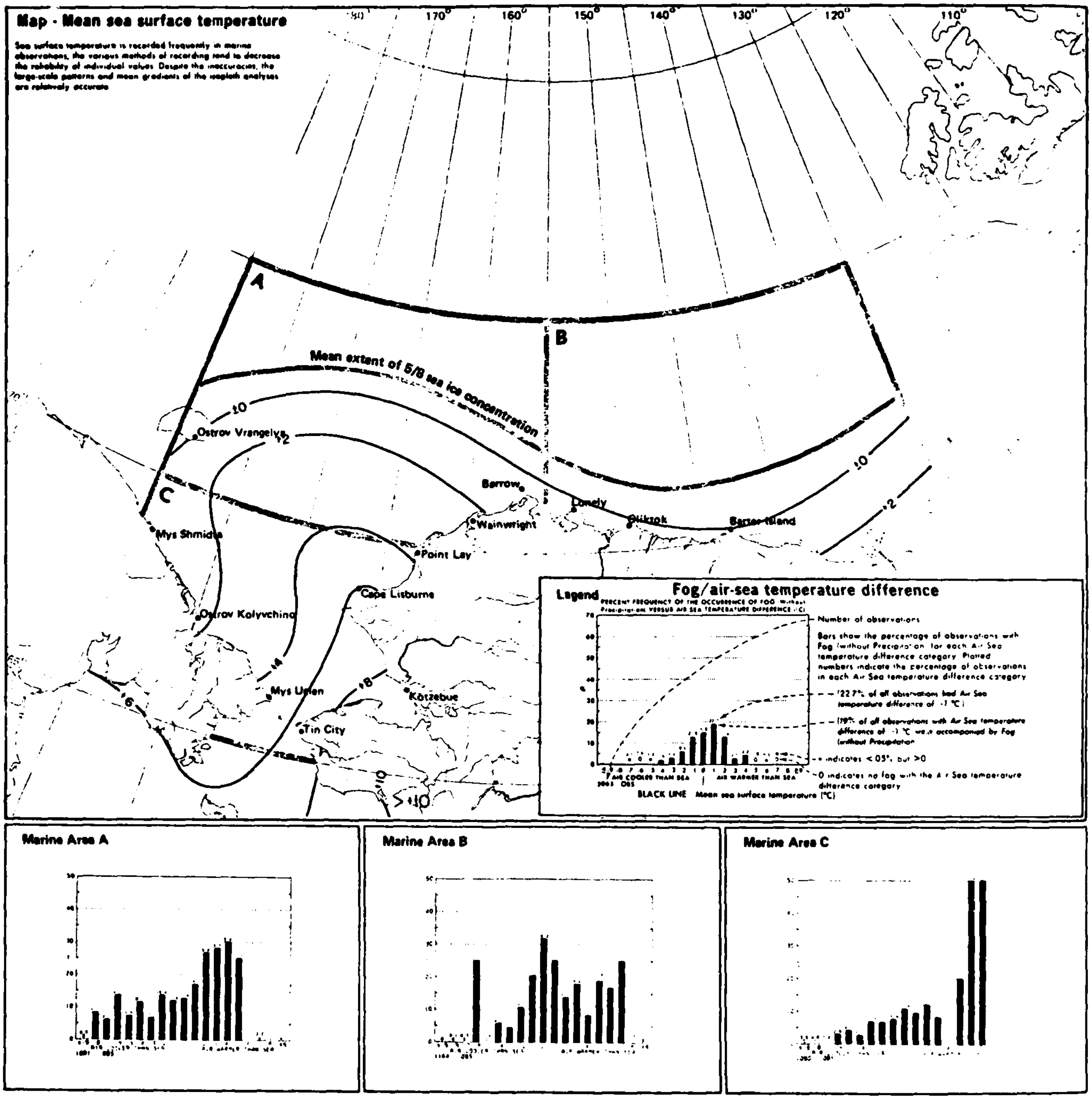


Figure 64. For/air-sea temperature difference, mean sea surface temperature, September (from Beaufort Sea ref. 2).

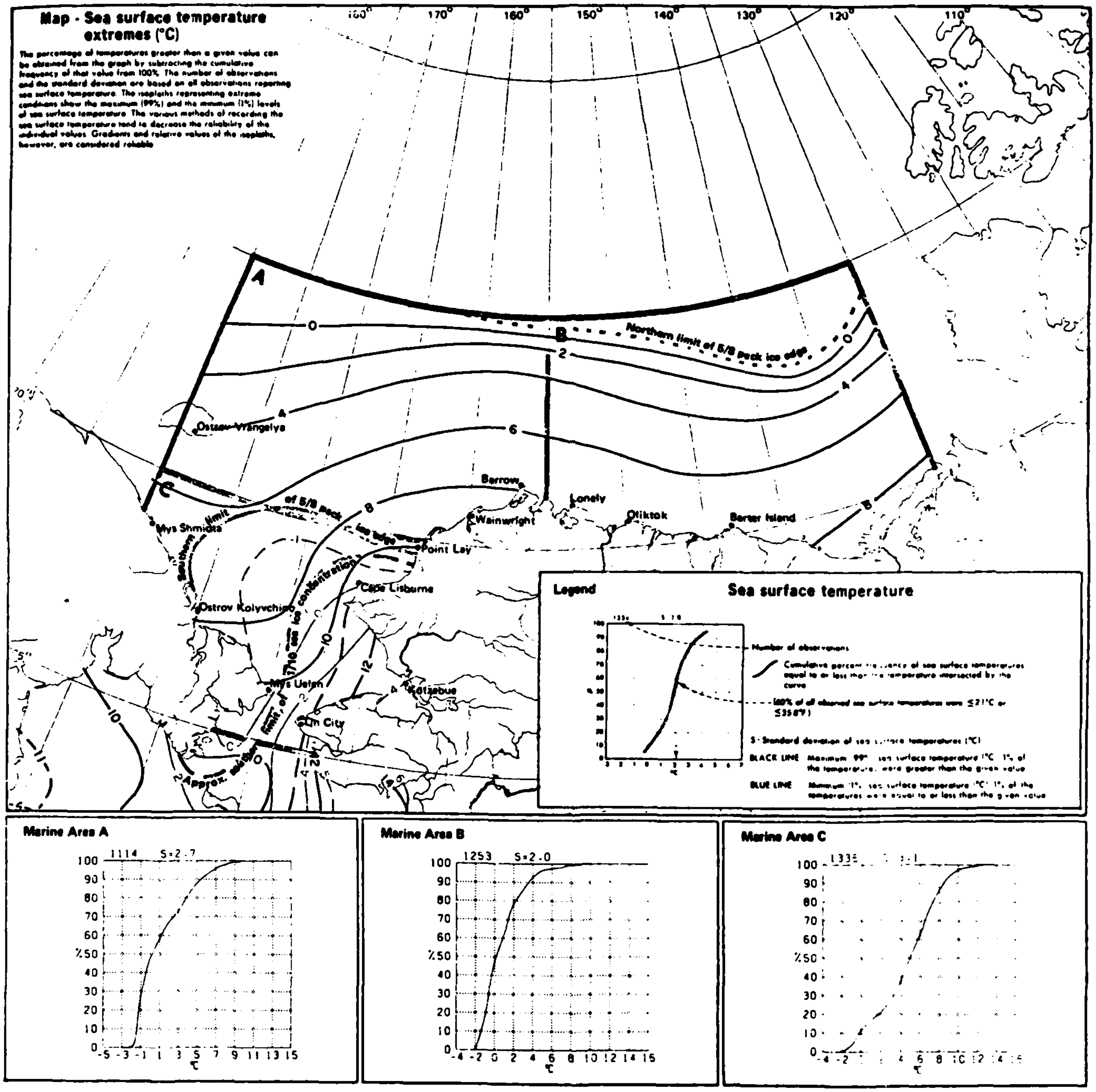


Figure 65. Séa surface temperature extremes, September (from Beaufort Sea ref. 2).

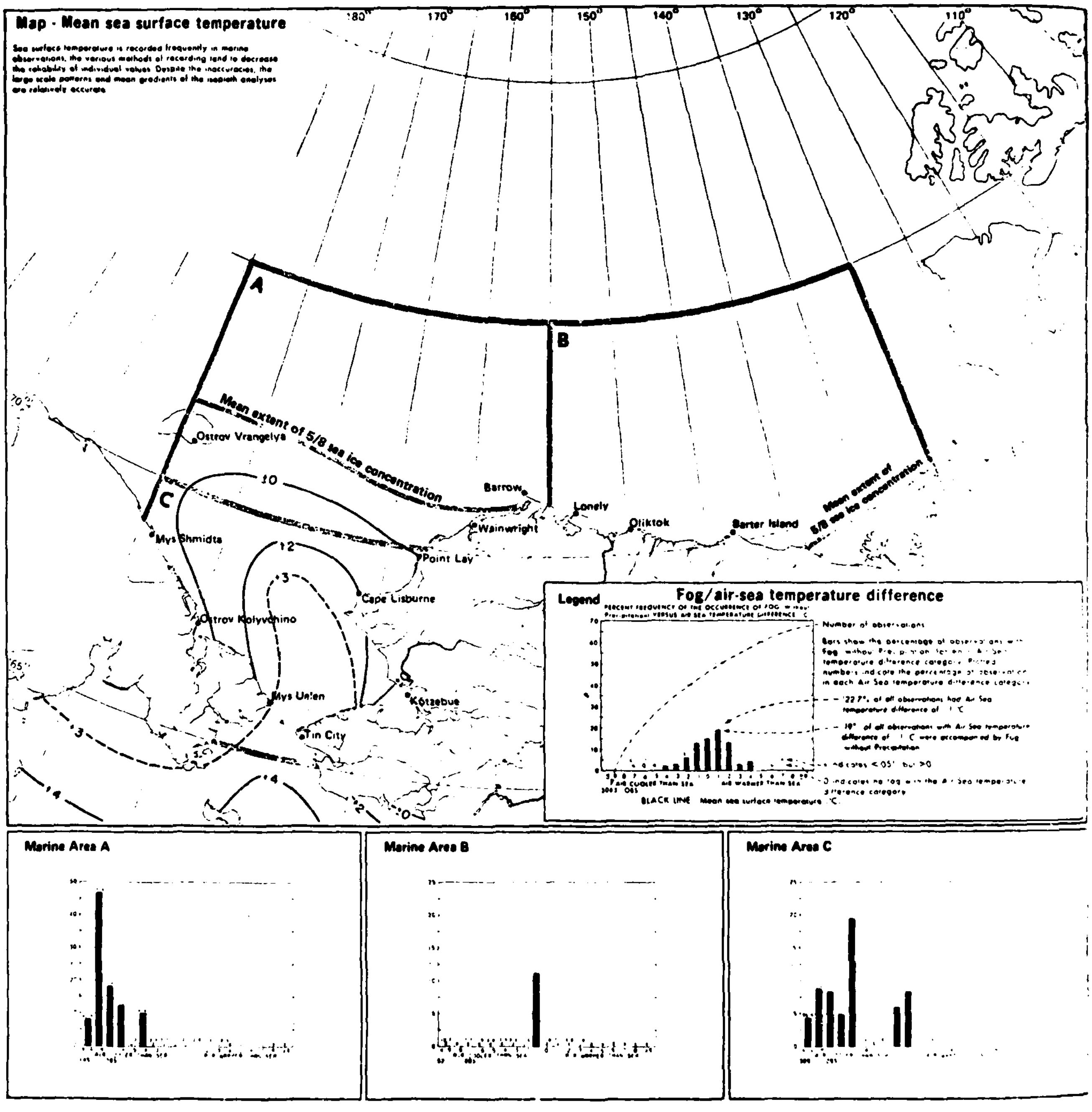


Figure 66. Fog/air-sea temperature difference, mean sea surface temperature, October (from Beaufort Sea ref. 2).

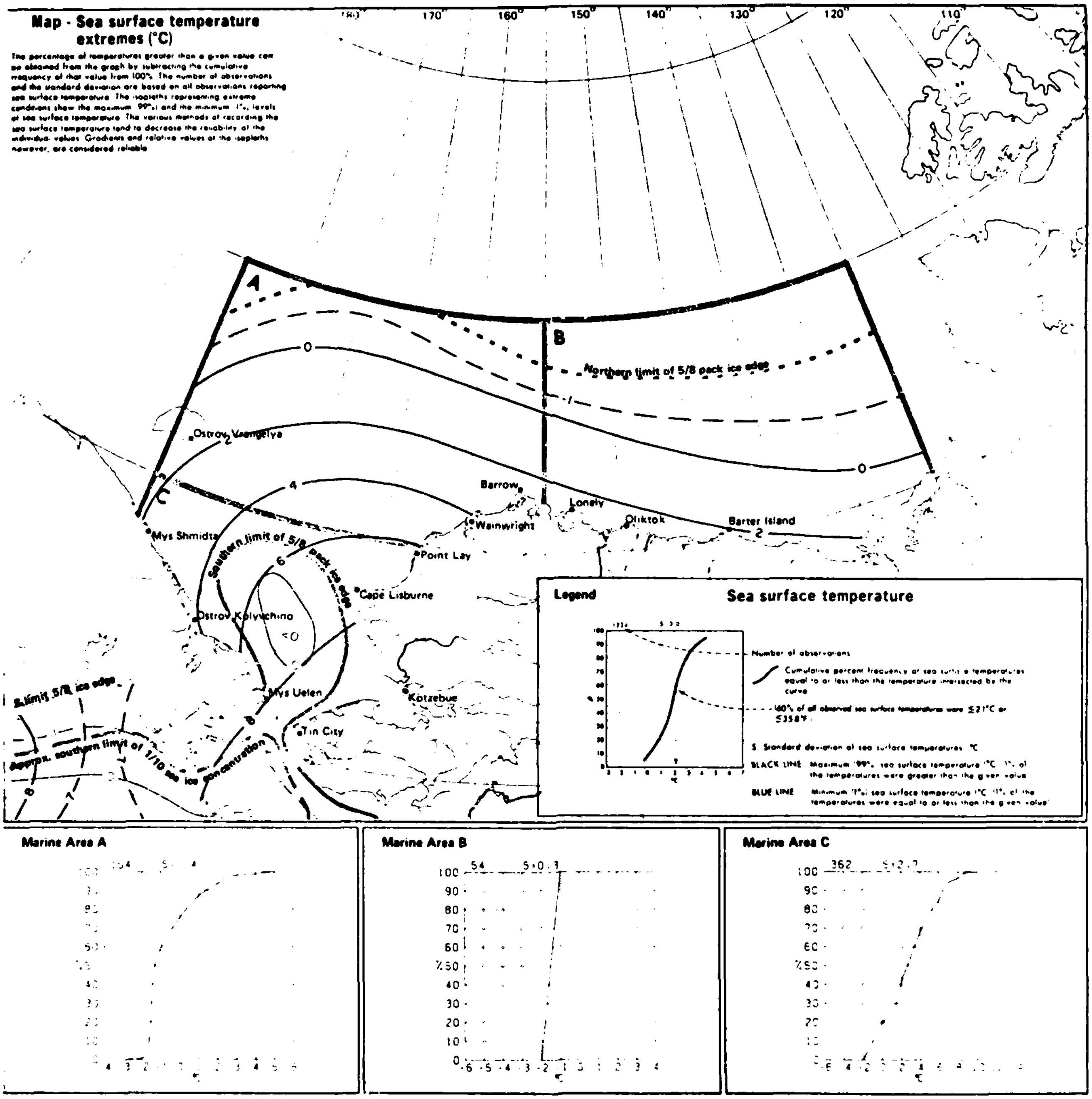


Figure 67. Sea surface temperature extremes, October (from Beaufort Sea ref. 2).

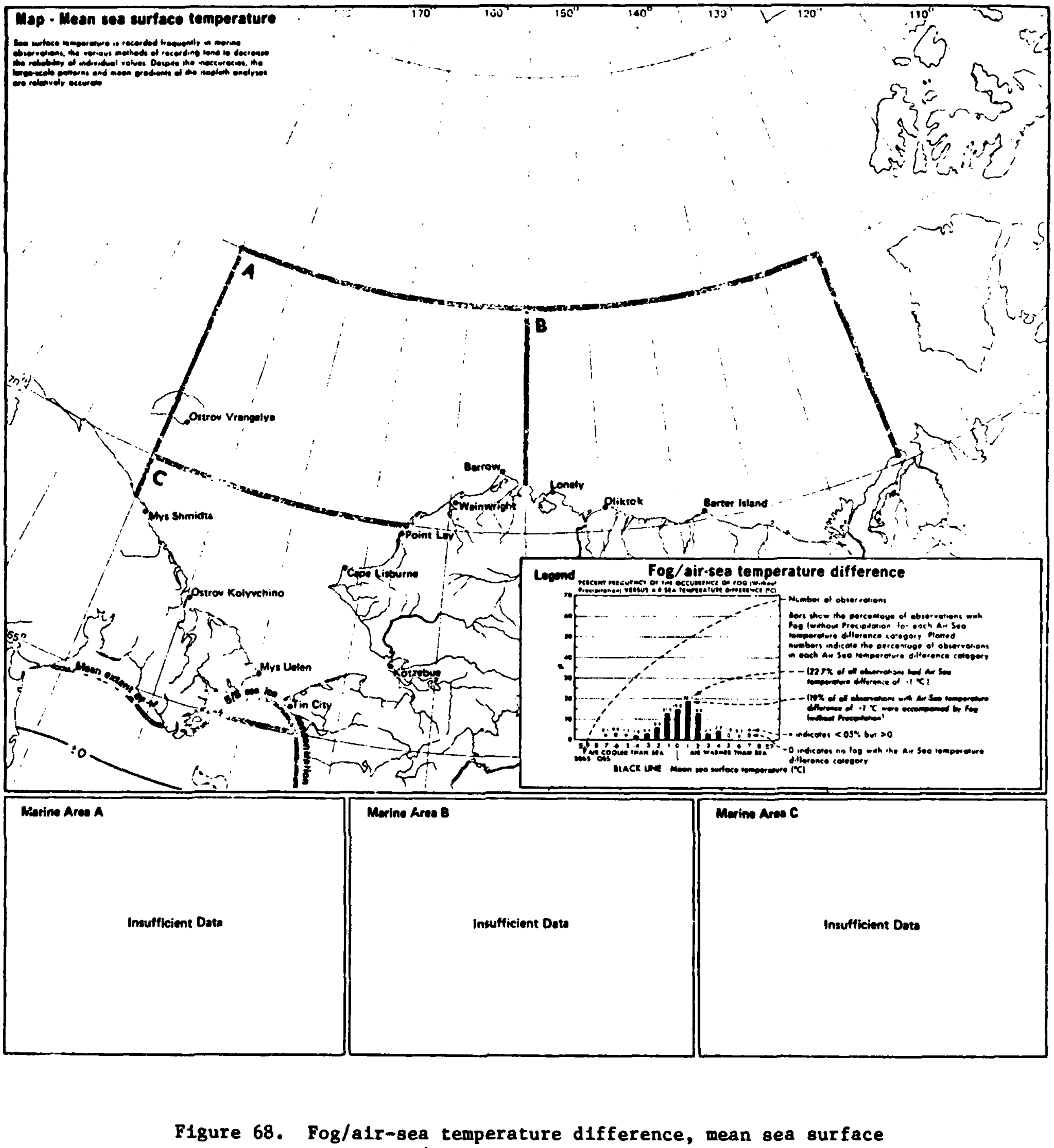


Figure 68. Fog/air-sea temperature difference, mean sea surface temperature, November (from Beaufort sea ref. 2).

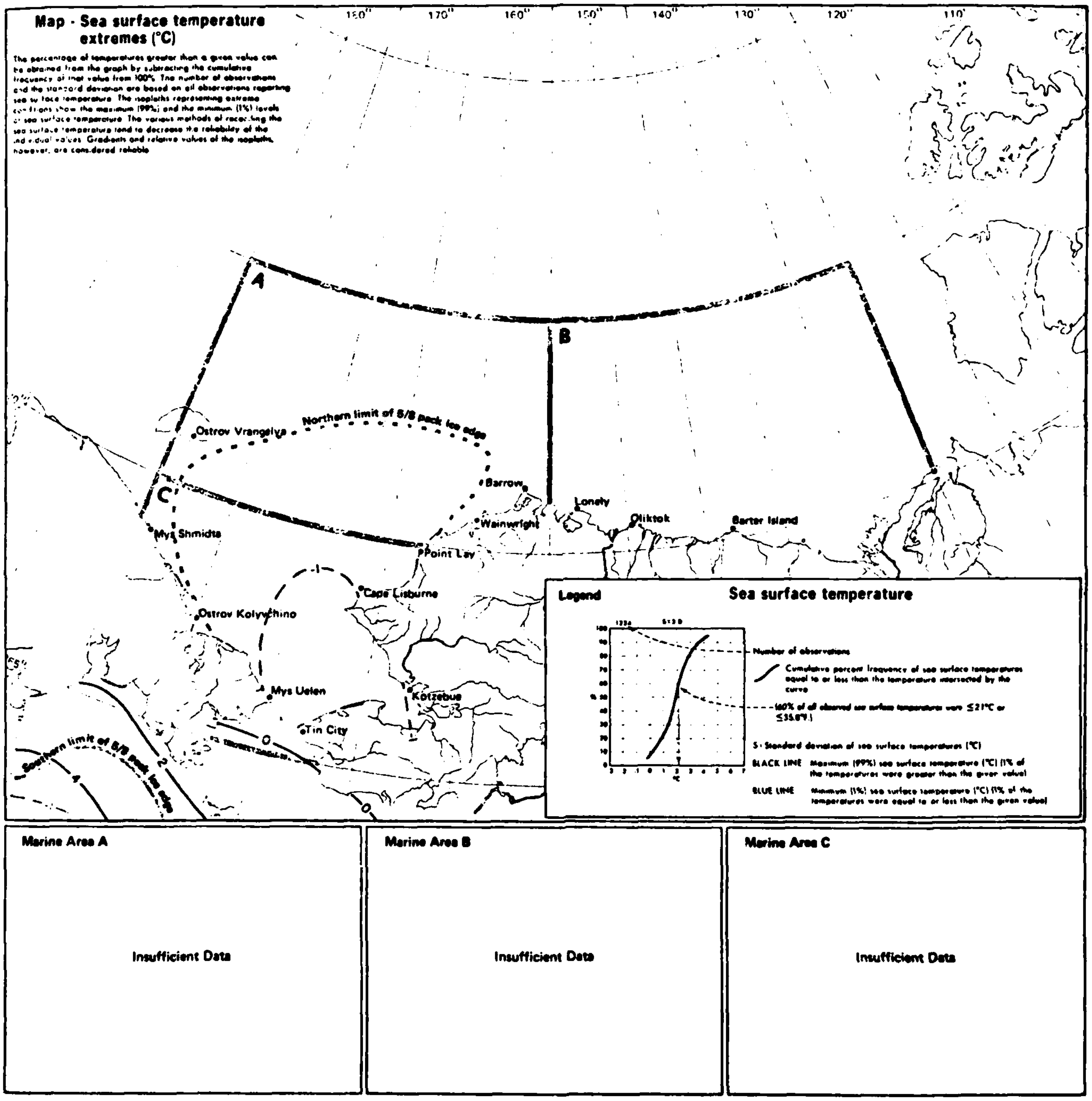


Figure 69. Sea surface temperature extremes, November (from Beaufort Sea ref. 2).

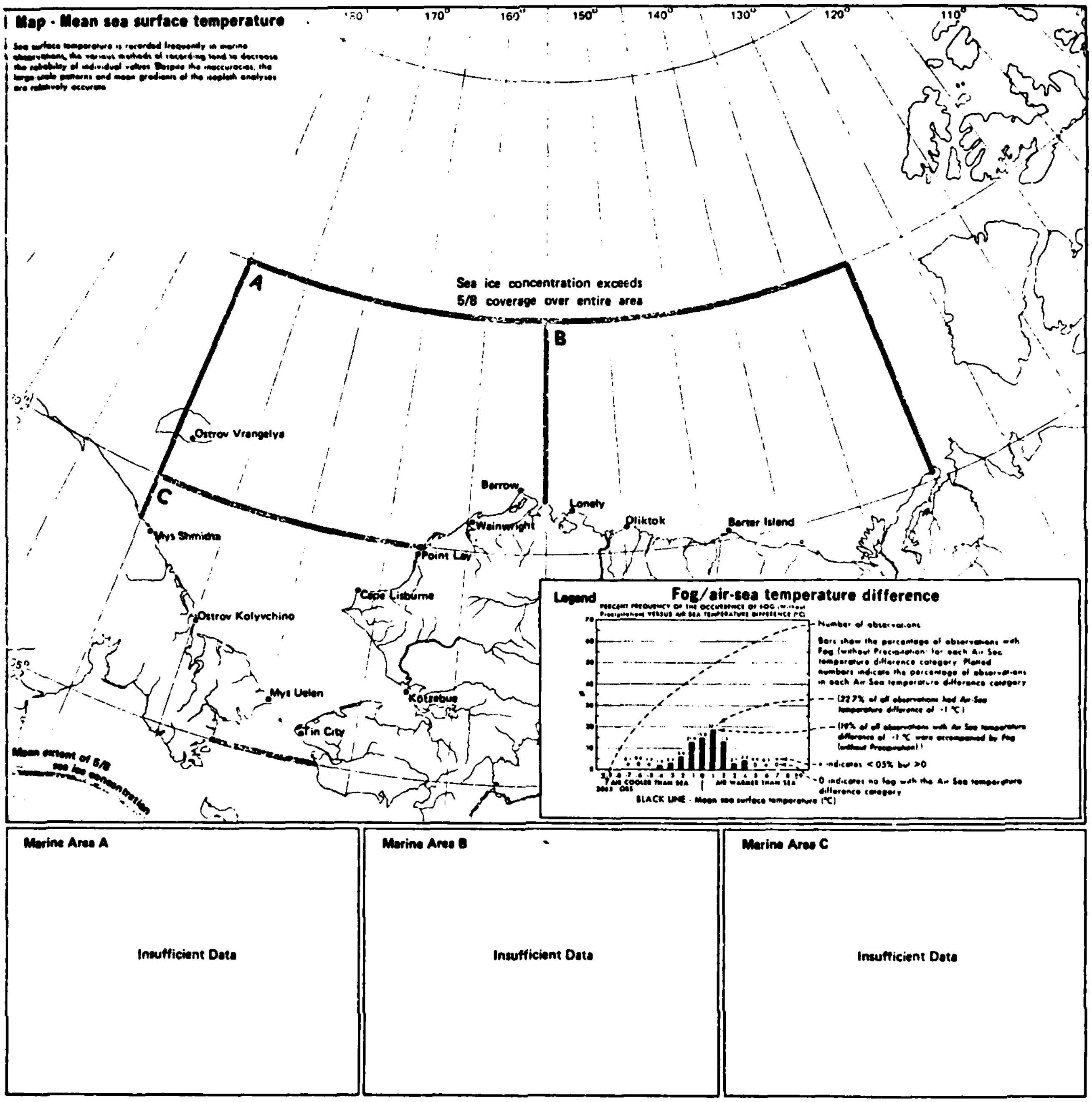


Figure 70. Fog/air-sea temperature difference, mean sea surface temperature, December (from Beaufort Sea ref. 2).

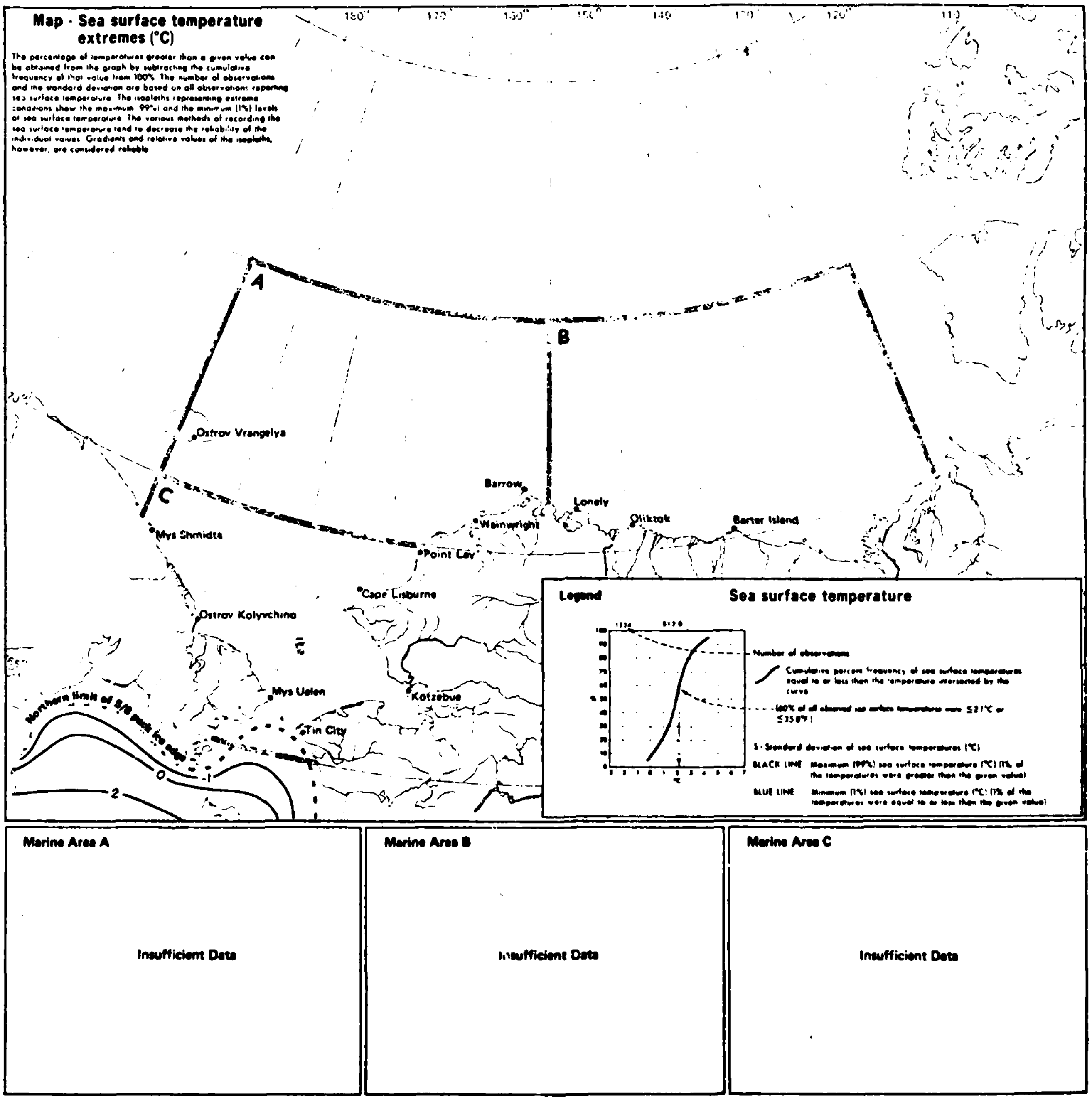


Figure 71. Sea surface temperature extremes, December (from Beaufort Sea ref. 2).

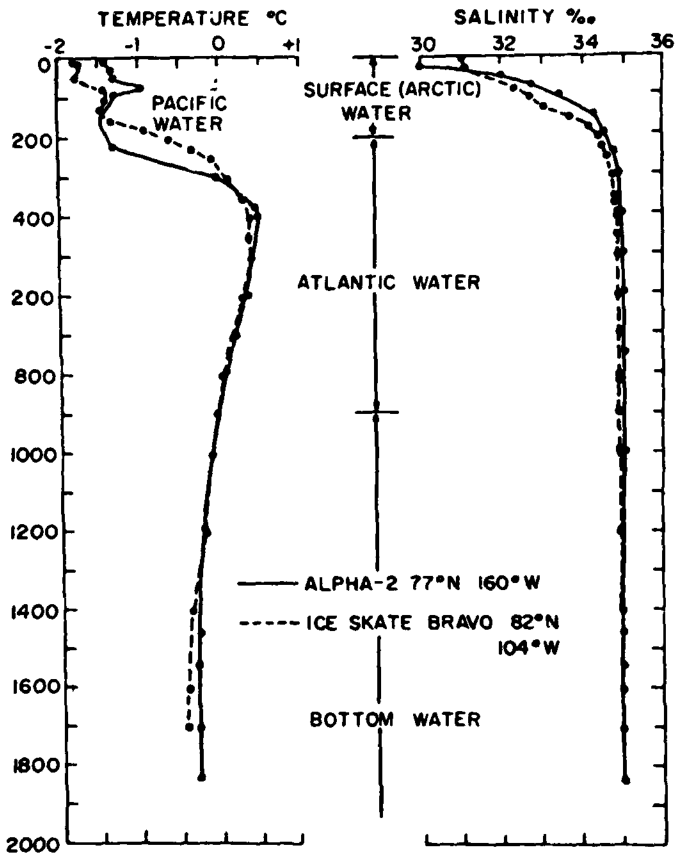


Figure 72. Profiles of temperature and salinity in the Arctic Ocean (from Beaufort Sea ref. 30).

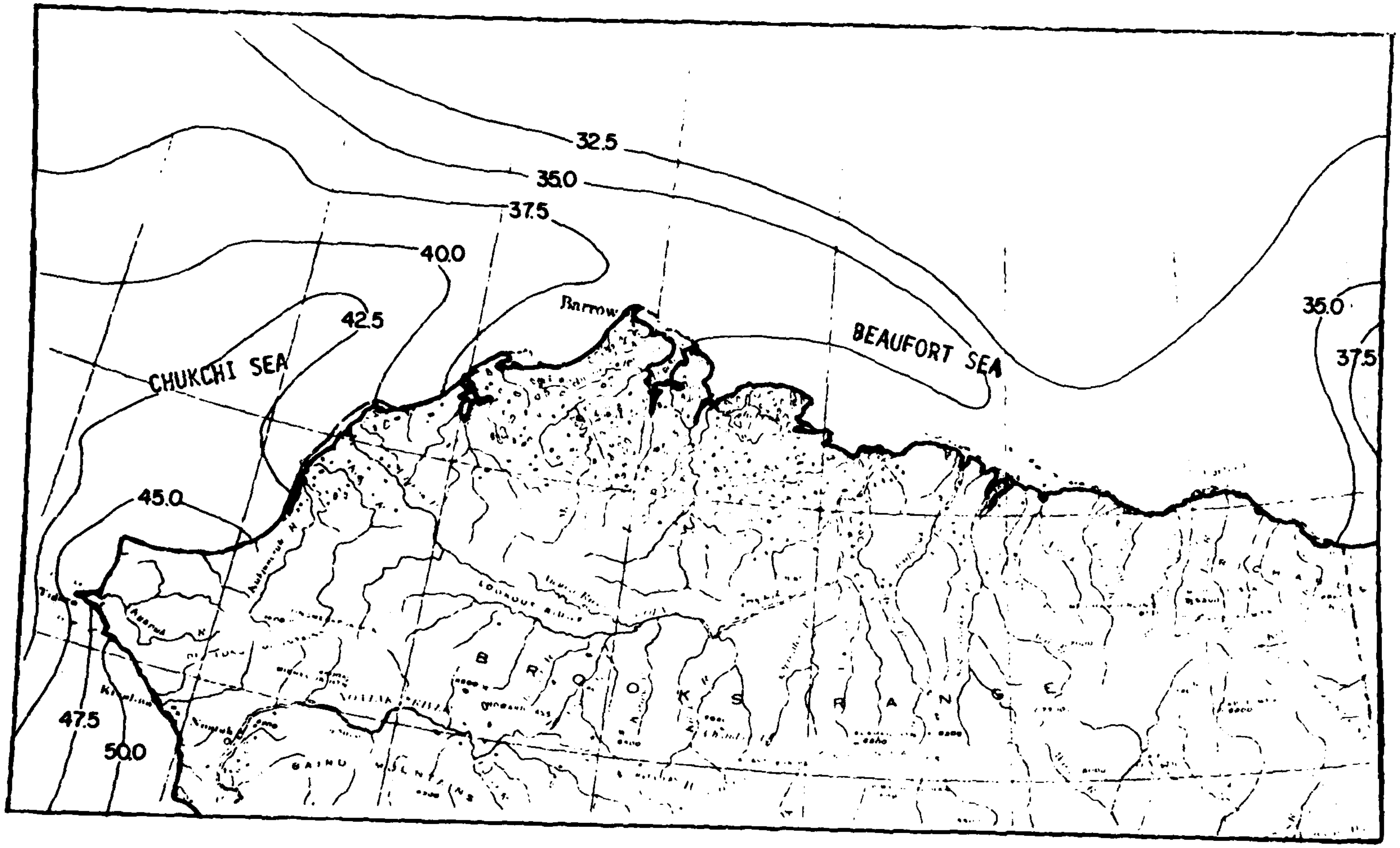


Figure 73. Average sea suriace temperature (^{o}F) for August (from Searby et al., 1971) (from Beaufort Sea ref. 20).

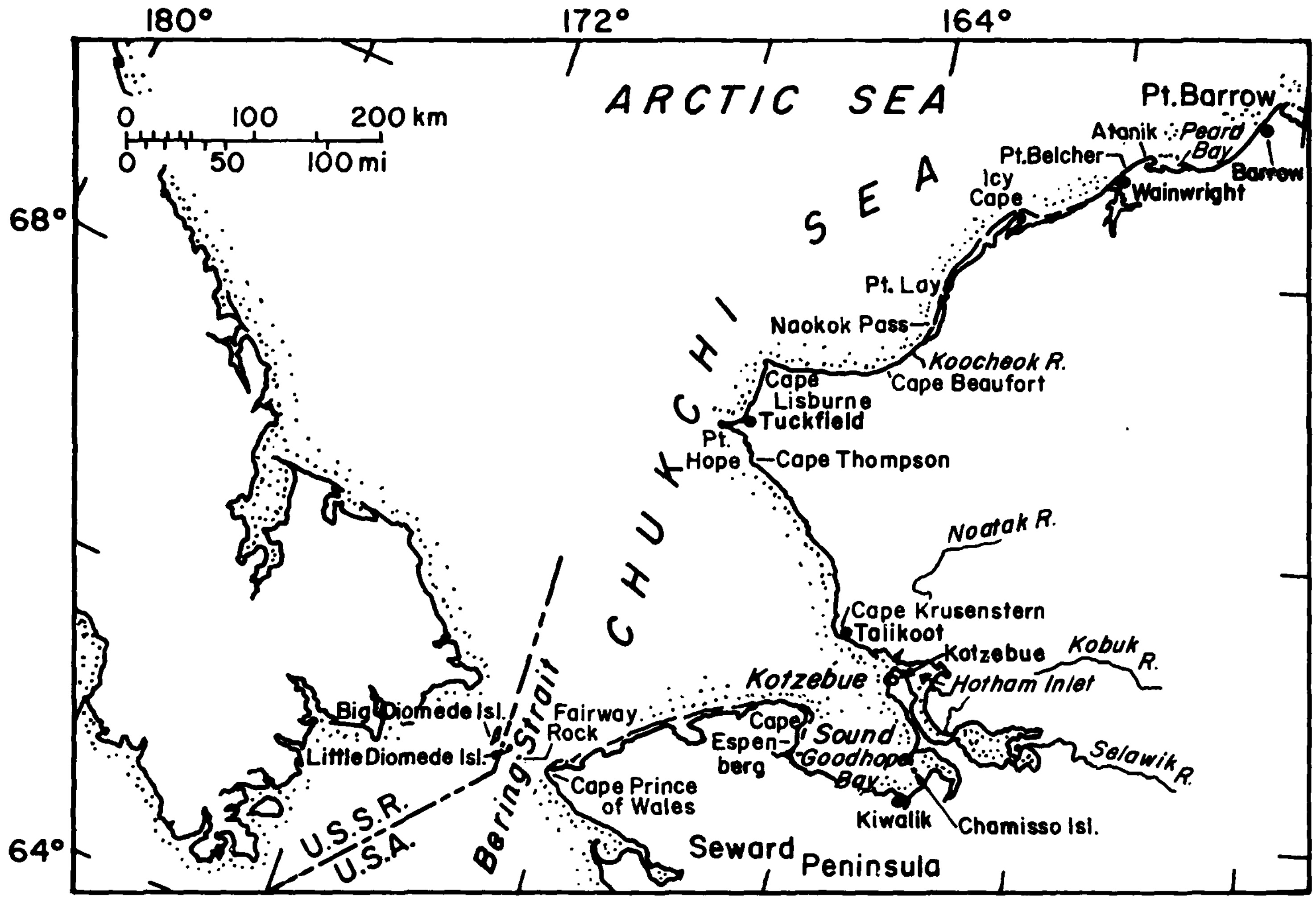


Figure 74. Chukchi Sea coast from Pt. Barrow to the Bering Strait.

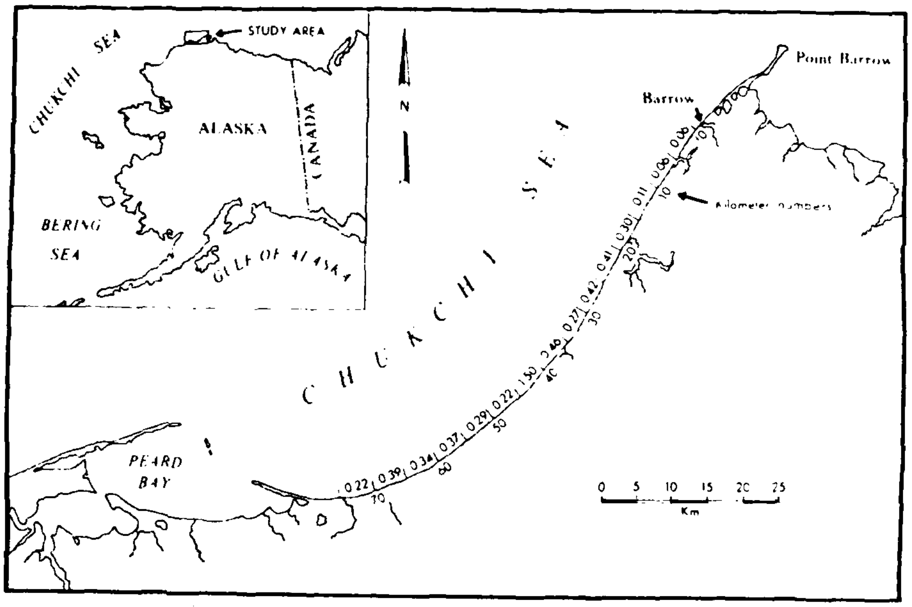


Figure 75. Location map of study area showing 5-km shoreline segments between Barrow and Peard Bay. Averaged erosion rates for each 5-km segment are listed in metres per year (from Chukchi Sea ref. 14).

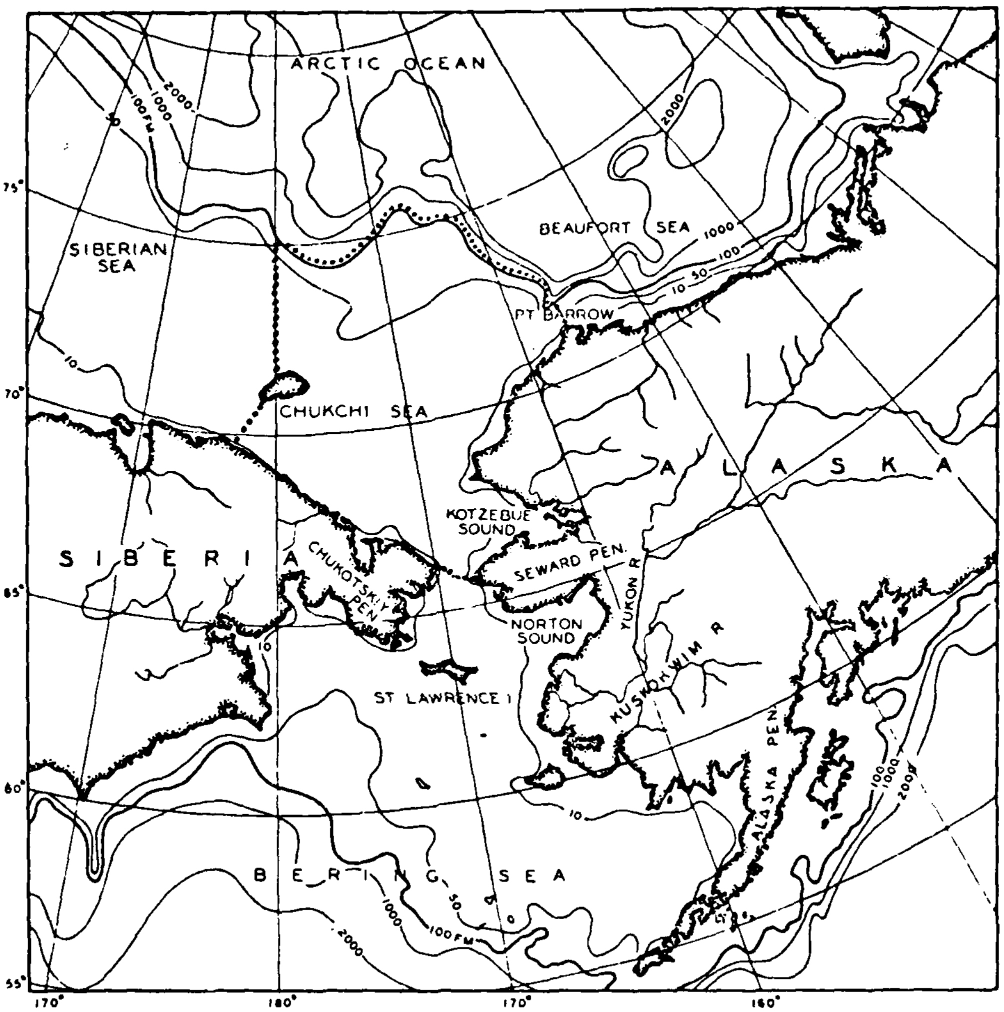


Figure 76. Location map showing the Bering-Chukchi platform (from Moore, 1964). Boundary of Chukchi Sea shown dotted. (By permission of the Macmillan Co., New York City). The "Siberian Sea" is better referred to as "East Siberian Sea" (from Chukchi Sea ref. 17).

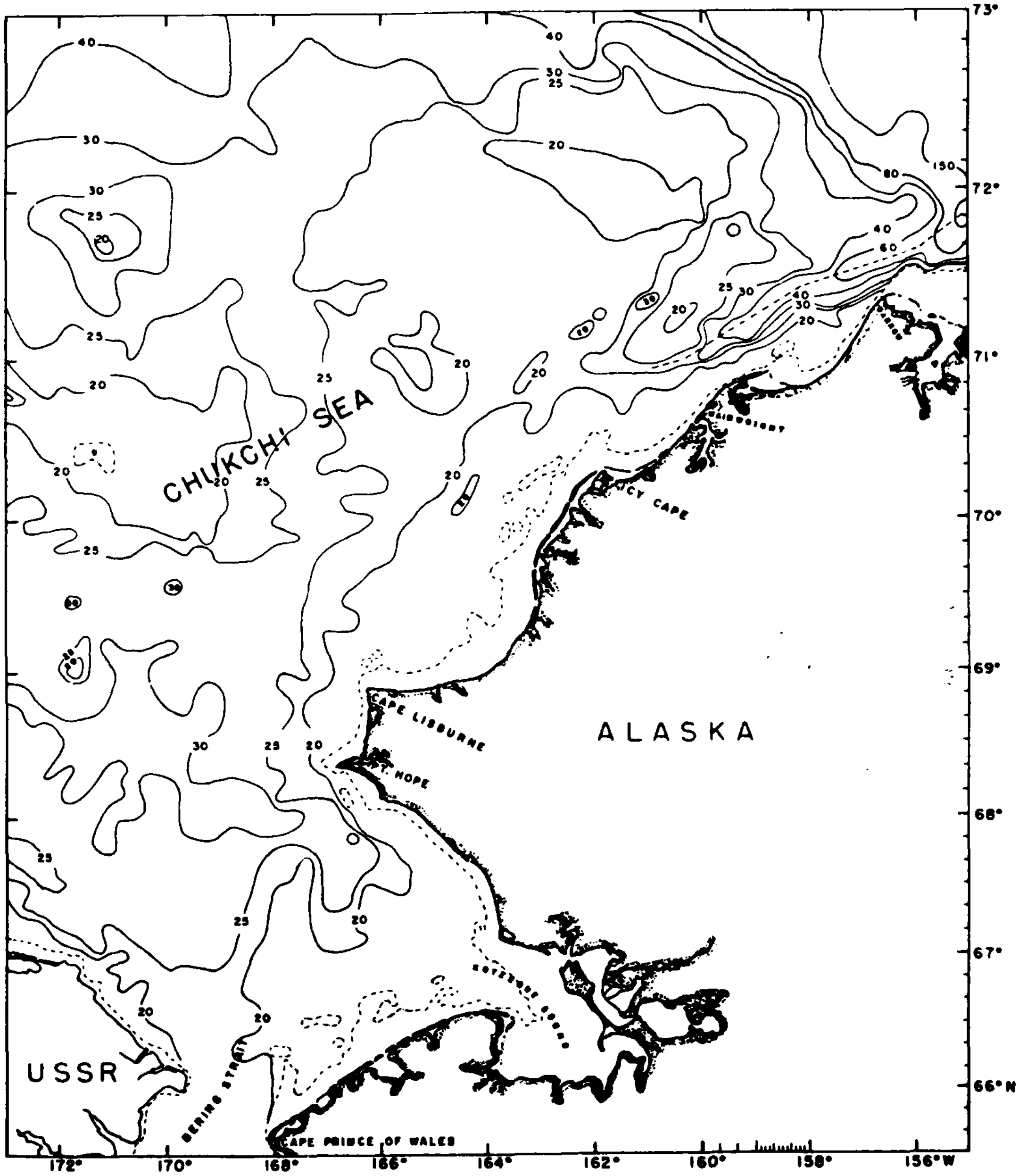
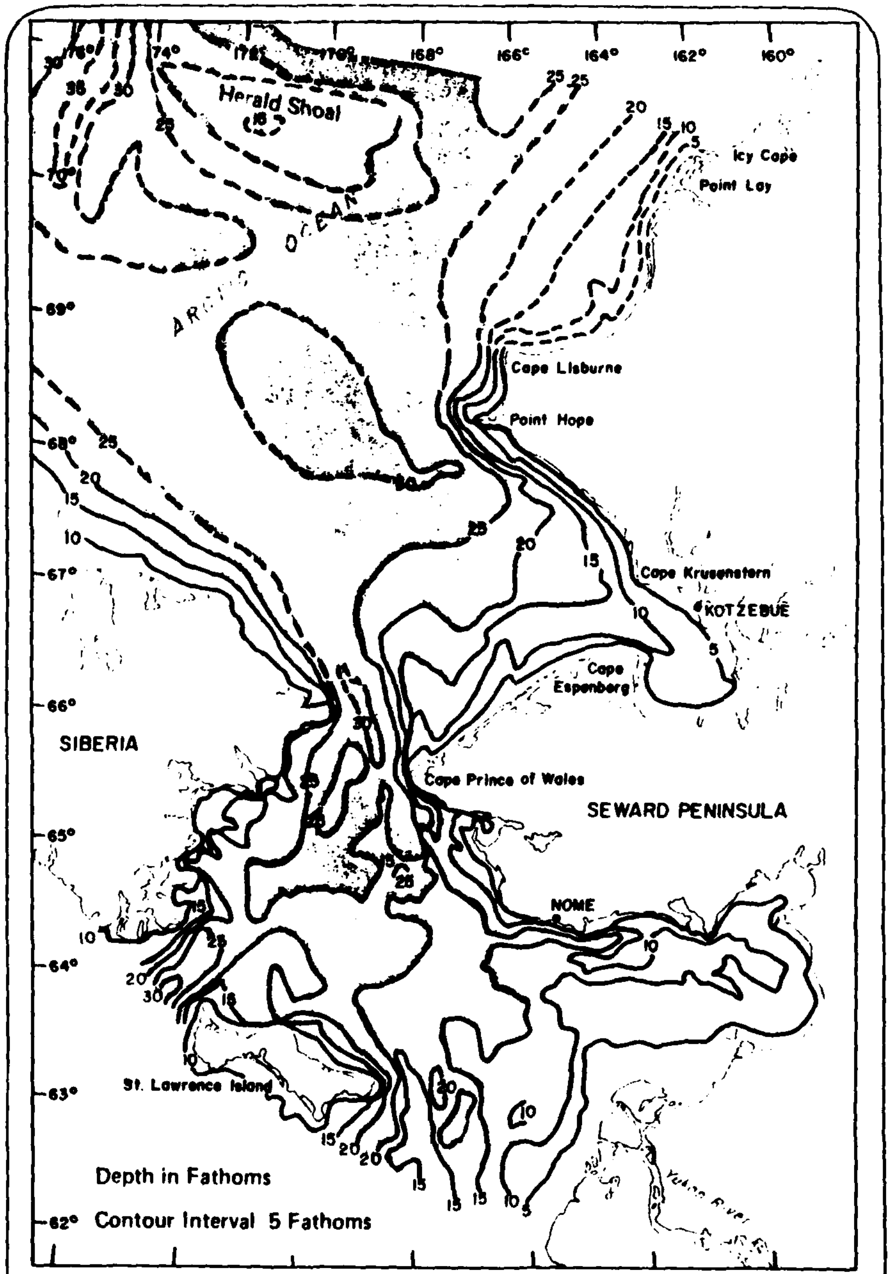


Figure 77. A map of the Mizpac area. The dashed line in the upper right corner indicates the axis of the Barrow Canyon. Bottom contours are in fathoms (1 fm = 1.83 m) (from Chukchi Sea ref. 18).



Source: R.H. Fleming and D. Heggarty, 1966. Oceanography of the Southeastern Chukchi Sea and M.L. Holmes, 1975. Tectonic Framework and Geologic Evolution of the Southern Chukchi Sea Continental Shelf.

Figure 78. Bathymetry (from Bering Sea ref. 1).

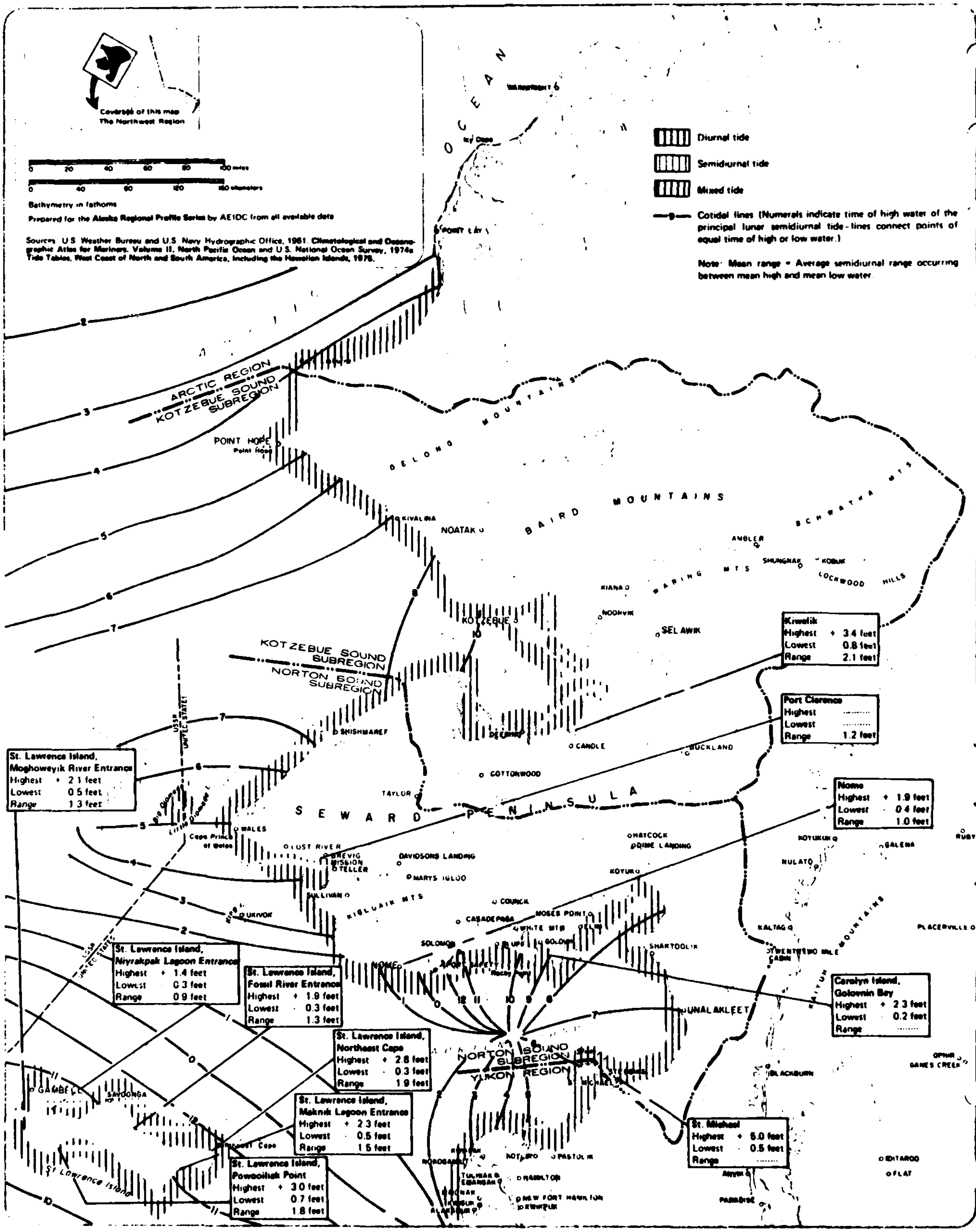


Figure 79. Tide data for selected locations, northwest region (from Chukchi Sea ref. 1).

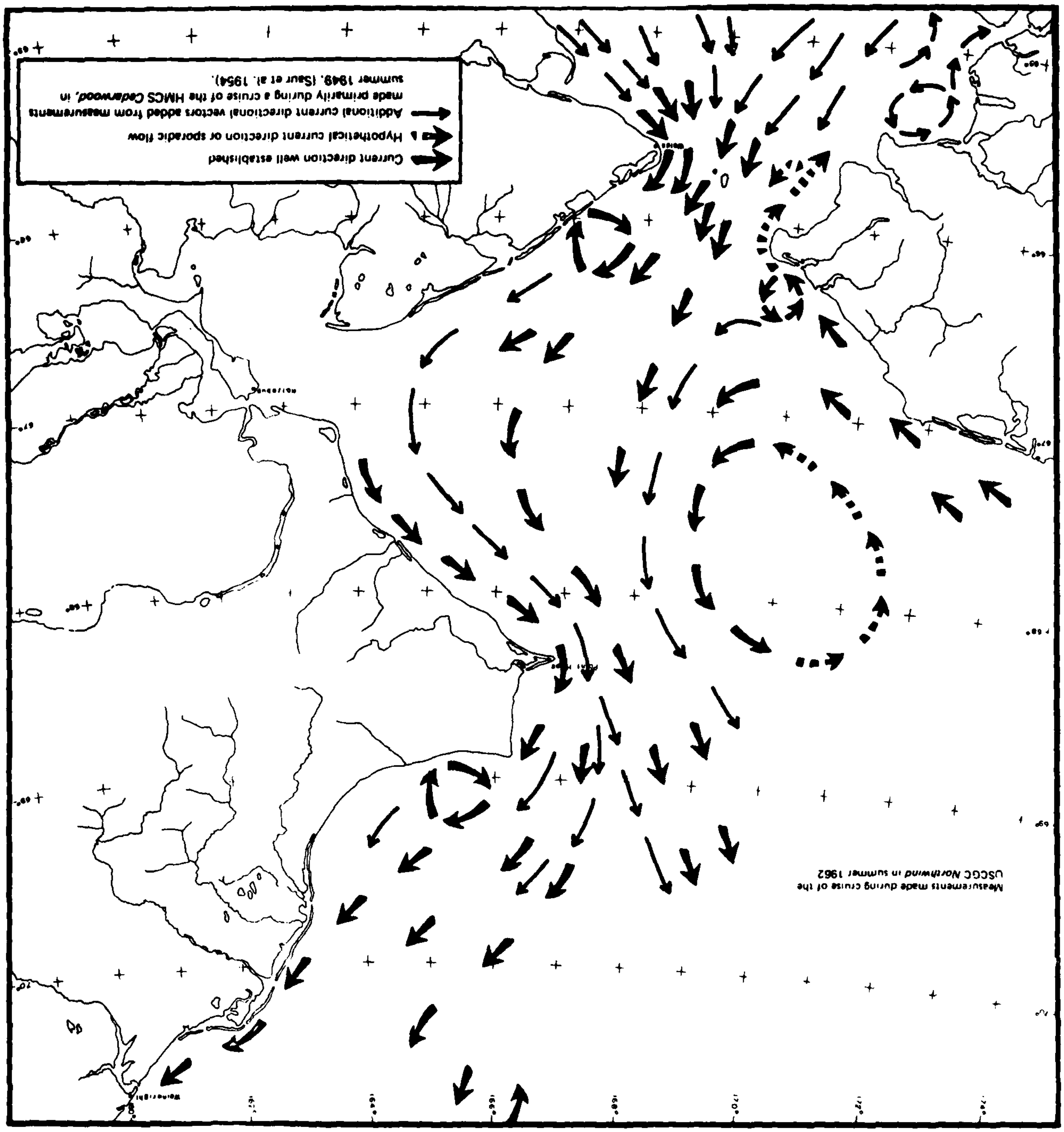


Figure 80. Summary of the apparent surface water circulation pattern in the Chukchi Sea during ice-free periods. (Aagaard and Coachman 1964) (from Chukchi Sea ref. 12).

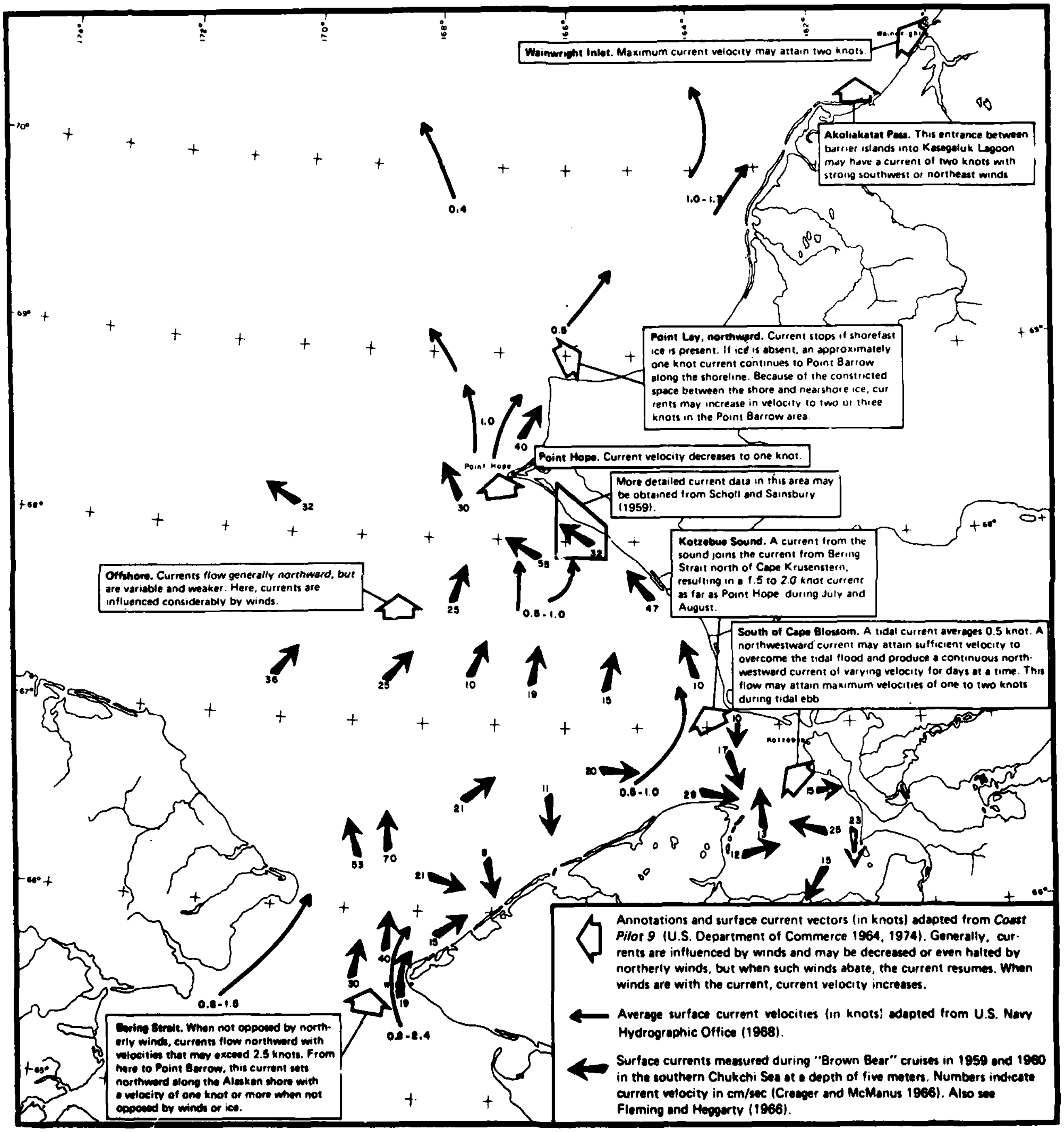


Figure 81. Surface circulation patterns in the Chukchi Sea during ice-free periods (from Chukchi Sea ref. 12).

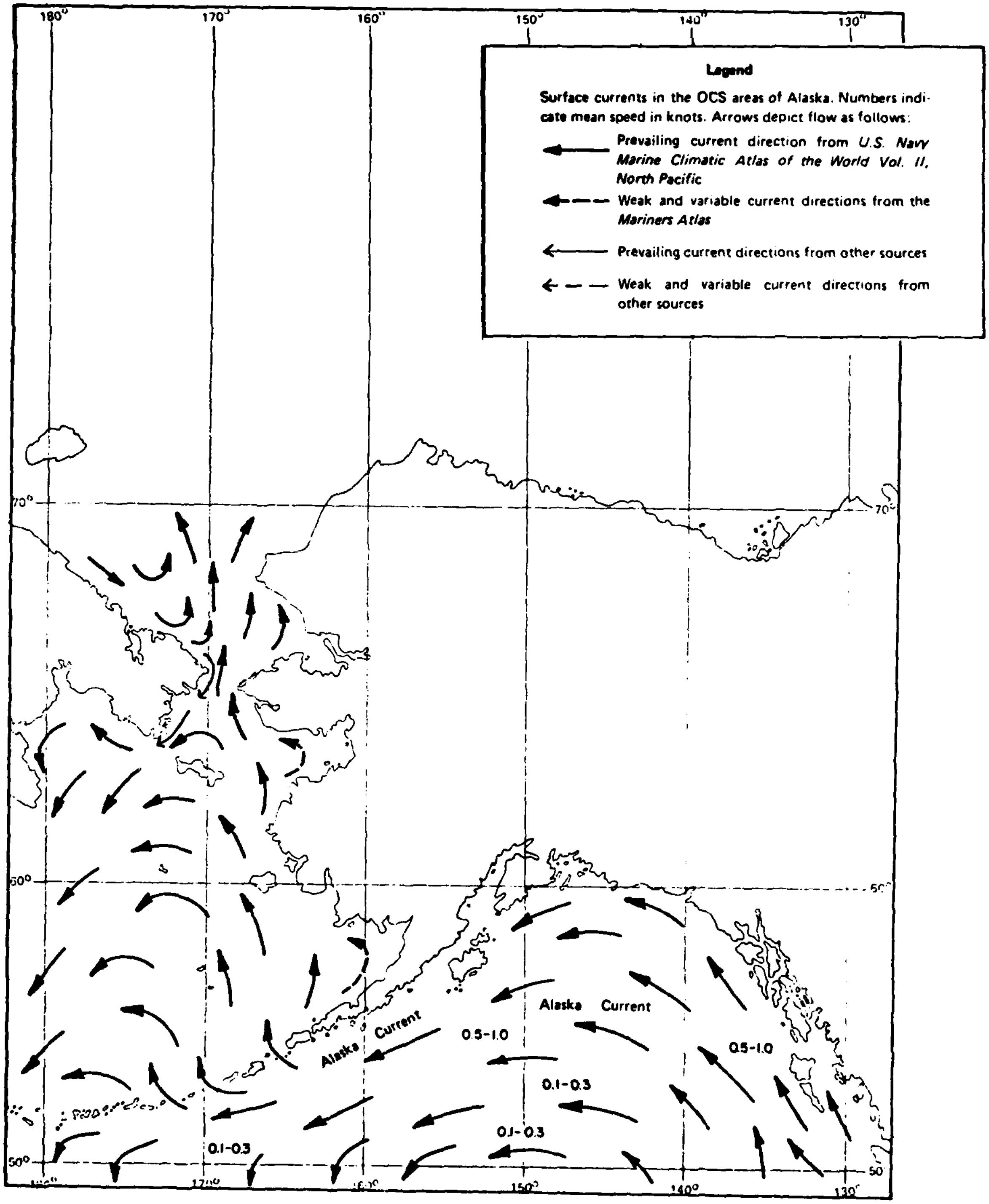


Figure 82. Winter sea surface currents (from Beaufort Sea ref. 2).

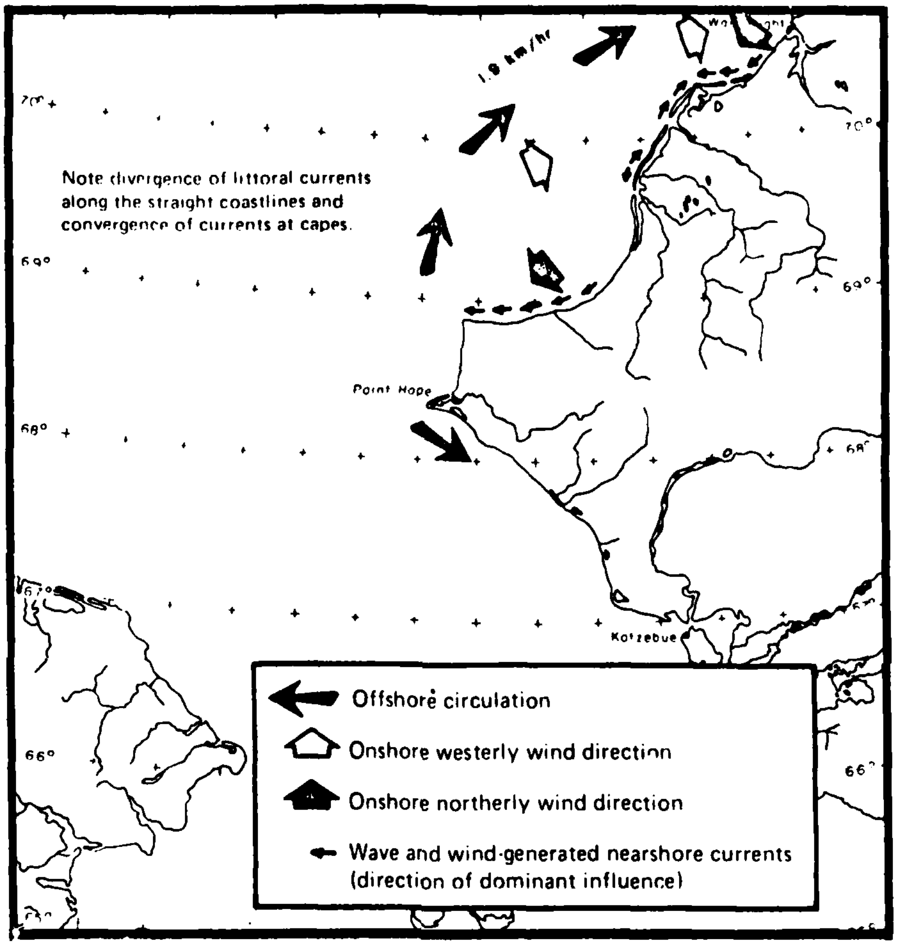


Figure 83. Nearshore surface currents in the northeast Chukchi Sea (Sellman et al. 1972; Wiseman et al. 1973) (from Chukchi Sea ref. 12).

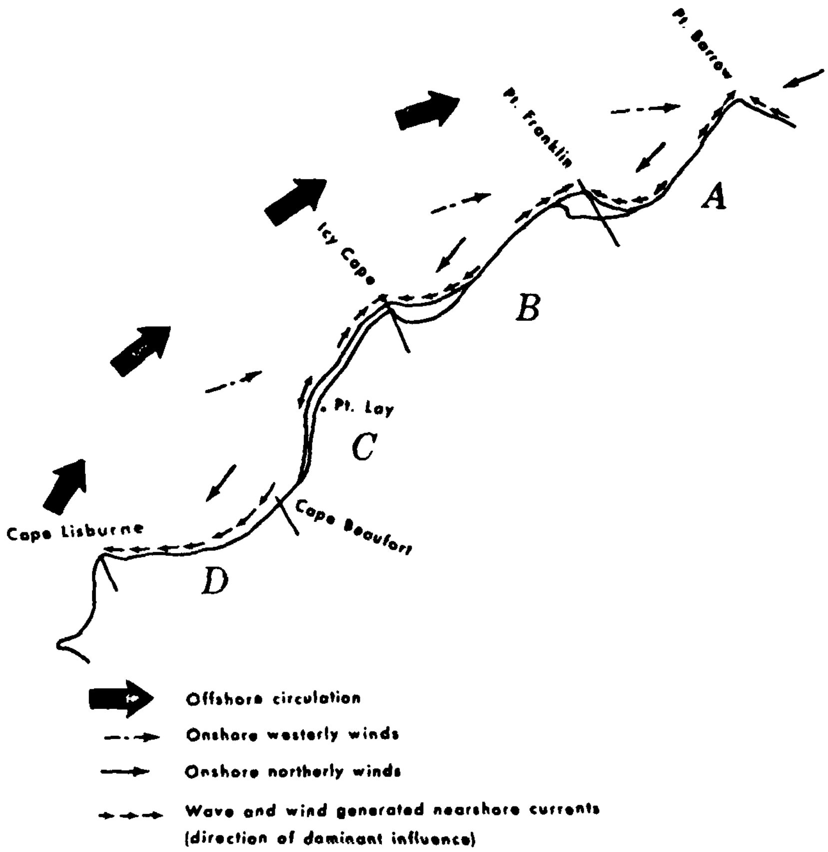


Figure 84. Diagrammatic representation of process regimes along the western Alaskan Arctic Coast. Areas A, B, and C are similar to "Carolina cape" systems, and area D has rocky shoreline. Note divergence of littoral currents along straight sectors and covergence of currents at the capes (from Chukchi Sea ref. 11).

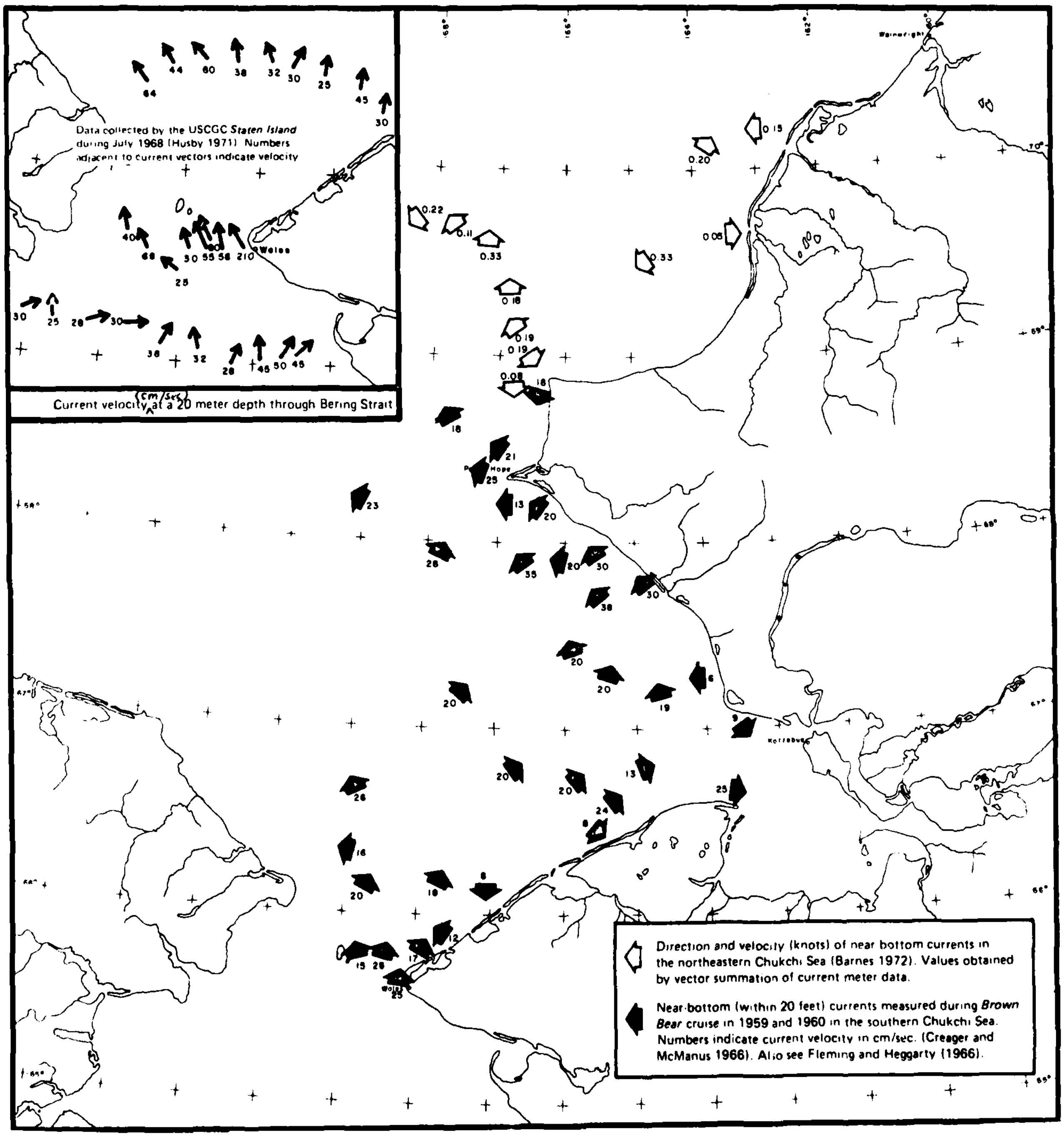


Figure 85. Near-bottom circulation patterns in the Chukchi Sea during ice-free periods (from Chukchi Sea ref. 12).

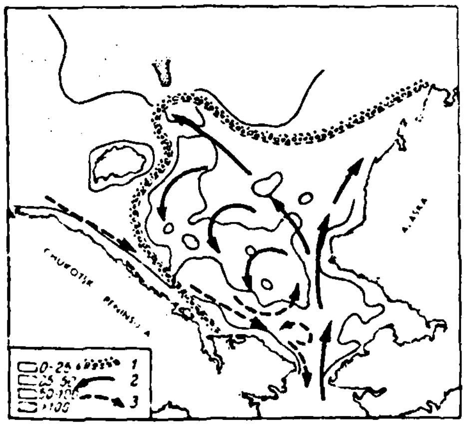


Figure 86. The Chukchi Sea showing depths, direction of the warm (2) and cold (3) currents and the summer boundary of the ice (1) from Zenkevich, 1963 (from Chukchi Sea ref. 17).

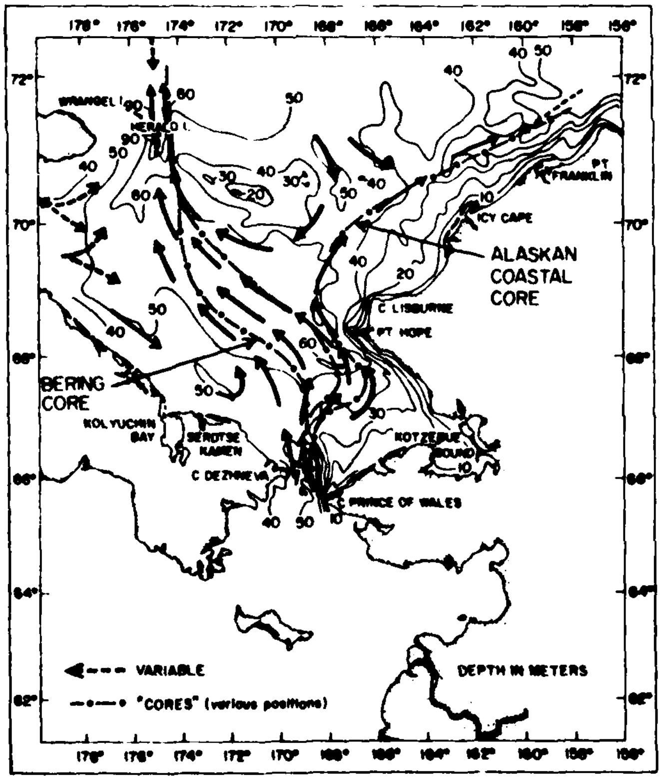


Figure 87. Schematic of lower layer flow in the Chukchi Sea. (Dotted arrows indicate variable currents. Various positions of "cores" of Bering Sea water mass are indicated.) (from Beaufort Sea ref. 16).

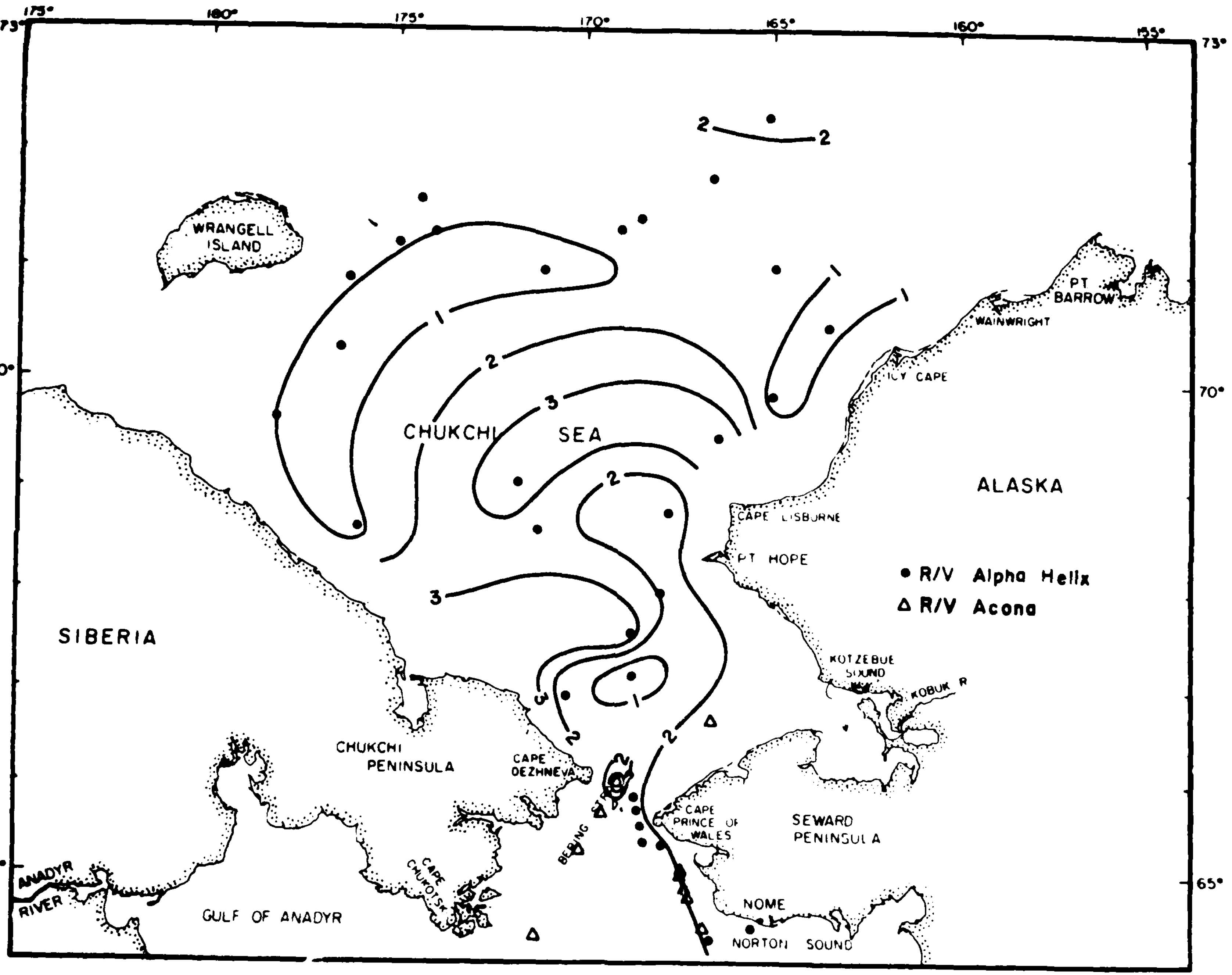


Figure 88. Surface suspended load distribution (mg/l) in the Chukchi Sea during 24-28 July 1973 (RV/ACONA) and 14 Aug. - 6 Sept. 1973 (RV/ALPHA

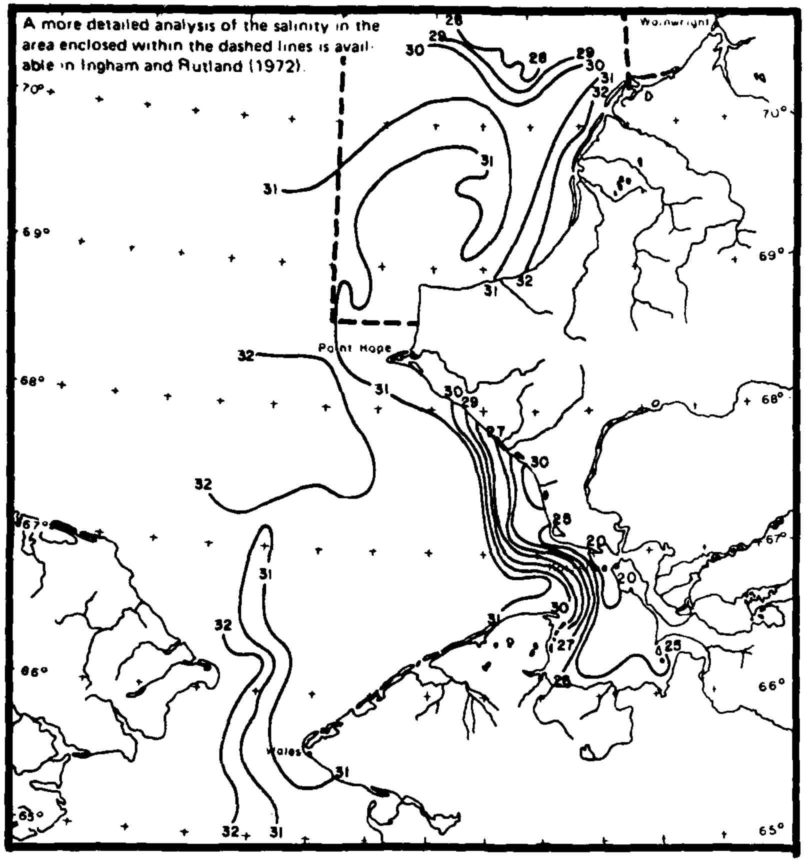


Figure 89. Surface salinity in 0/00.

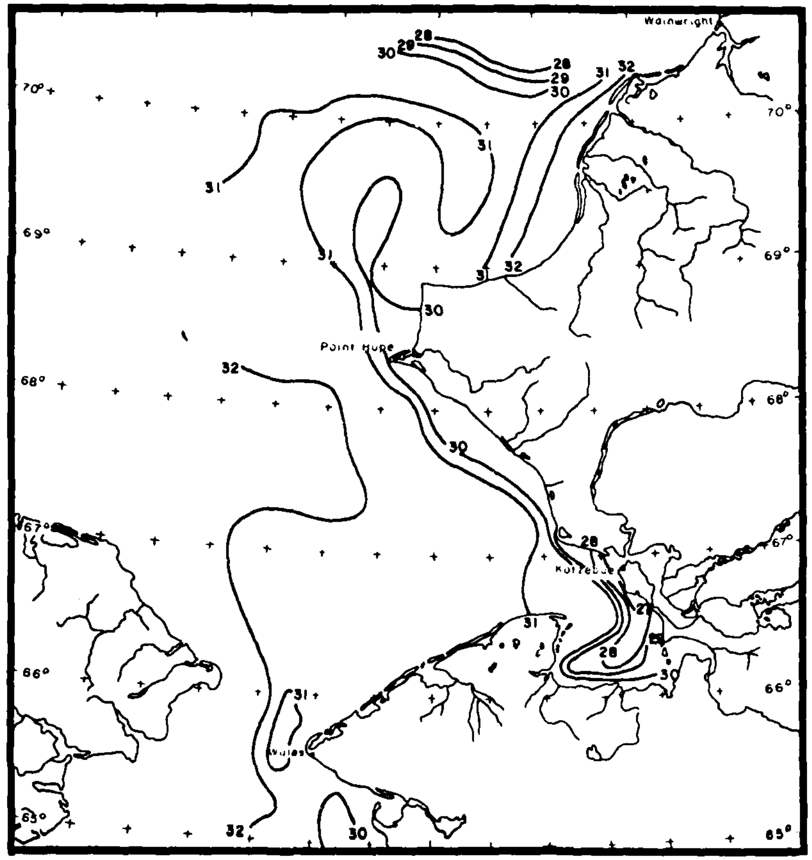


Figure 90. Salinities in 0/00 at 5 meter depth.

Figures 89 through 91 illustrate the summer salinity regime during 1959 and 1960. Waters at all depths adjacent to the Alaskan coast are dilute (less than 31 0/00 at all depths (Fleming and Heggarty 1966). A more detailed analysis of the salinity regime of the northeast Chukchi Sea during fall of 1970 is available in Ingham and Rutland (1972), shown outlined in dashed lines on Figure 89 (from Chukchi Sea ref. 12).

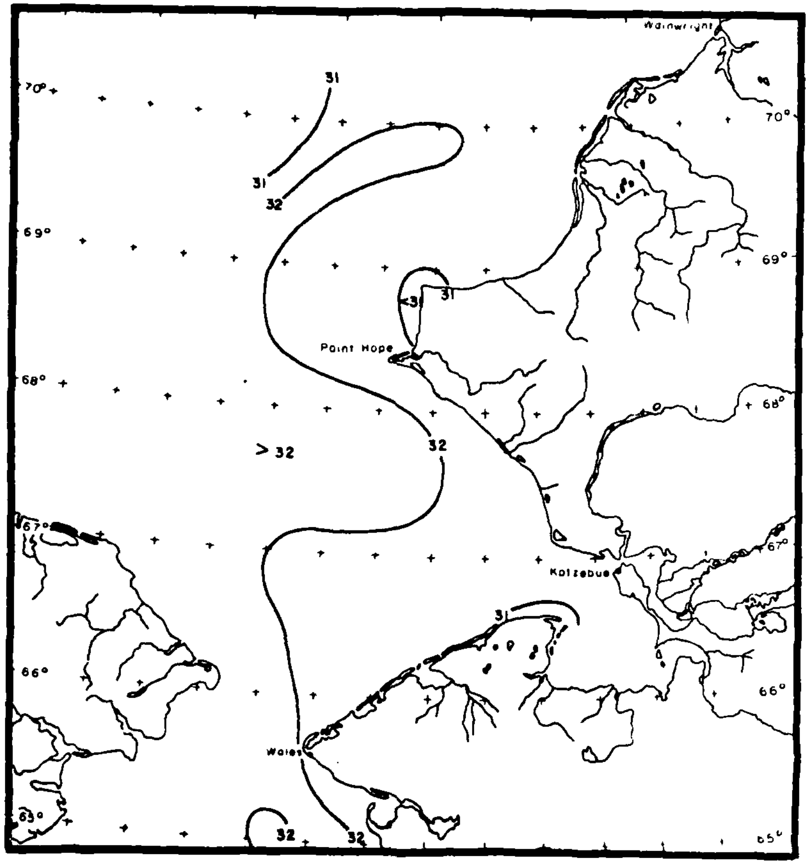


Figure 91. Salinities in $^{o}/oo$ at 20-meter depth.

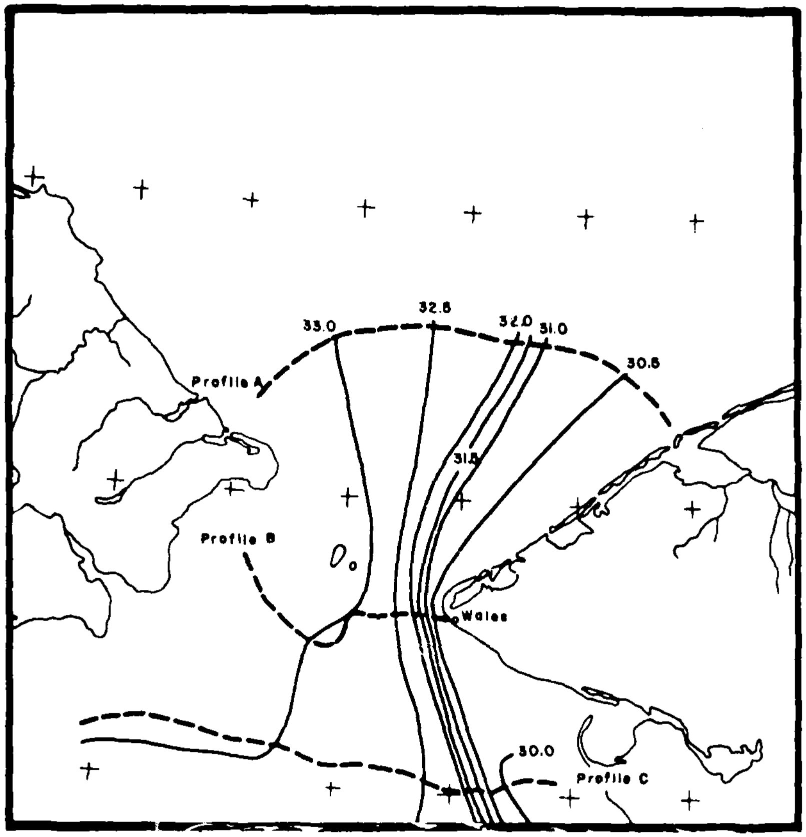


Figure 92. Surface salinities in $^{o}/oo$. Vertical salinity profiles A, B and C are illustrated on Figures 6, 7 and 8.

Figures 92 and 93 illustrate the salinity regime in Bering Strait in summer 1968 (Husby 1971) (from Chukchi Sea ref. 12).

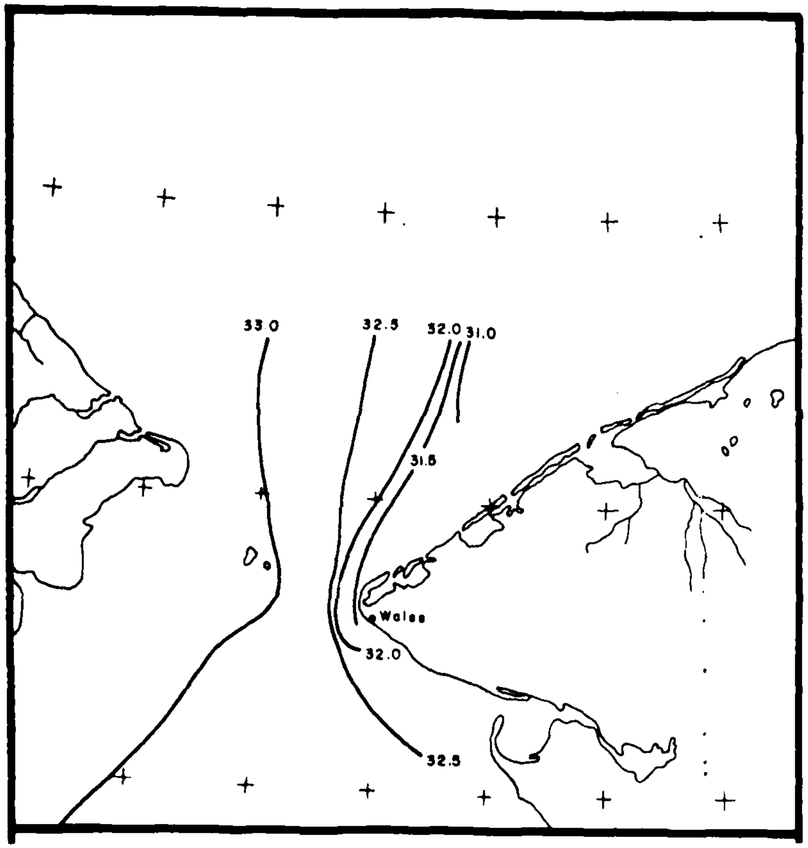


Figure 93. Salinities in $^{o}/oo$ at 20-meter depth.

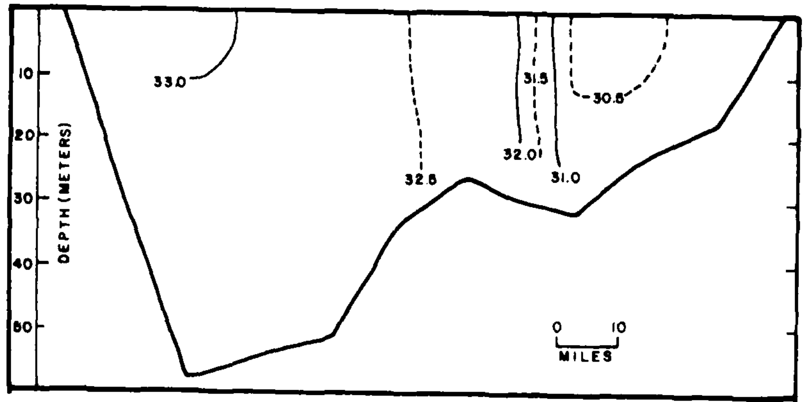


Figure 94. Vertical salinity regime in $^{o}/oo$ along Profile A.

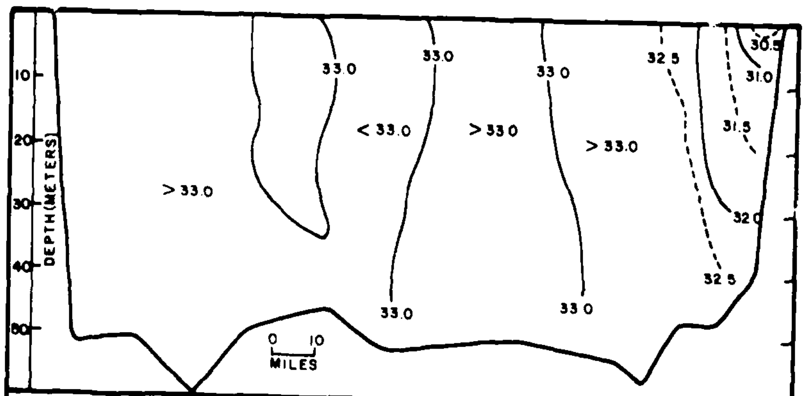


Figure 95. Vertical salinity regime in $^{o}/oo$ along Profile B.

Figures 94 through 96 illustrate cross sectional salinity profiles through the Bering Strait area as indicated in dashed lines on Figure 92 (Husby 1971) (from Chukchi Sea ref. 12).

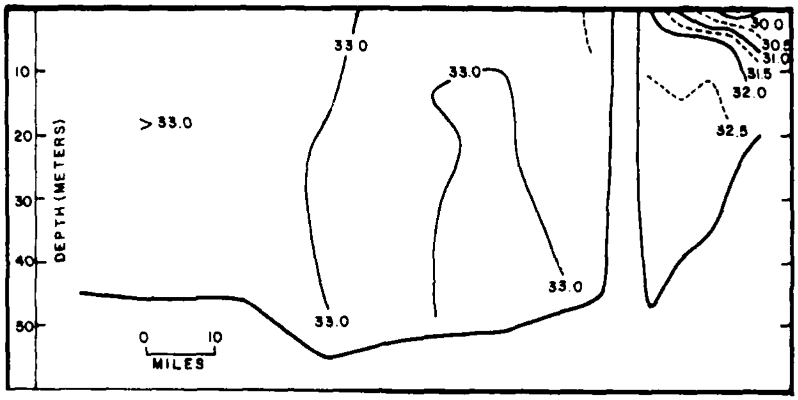


Figure 96. Vertical salinity regime in $^{o}/oo$ along Profile C.

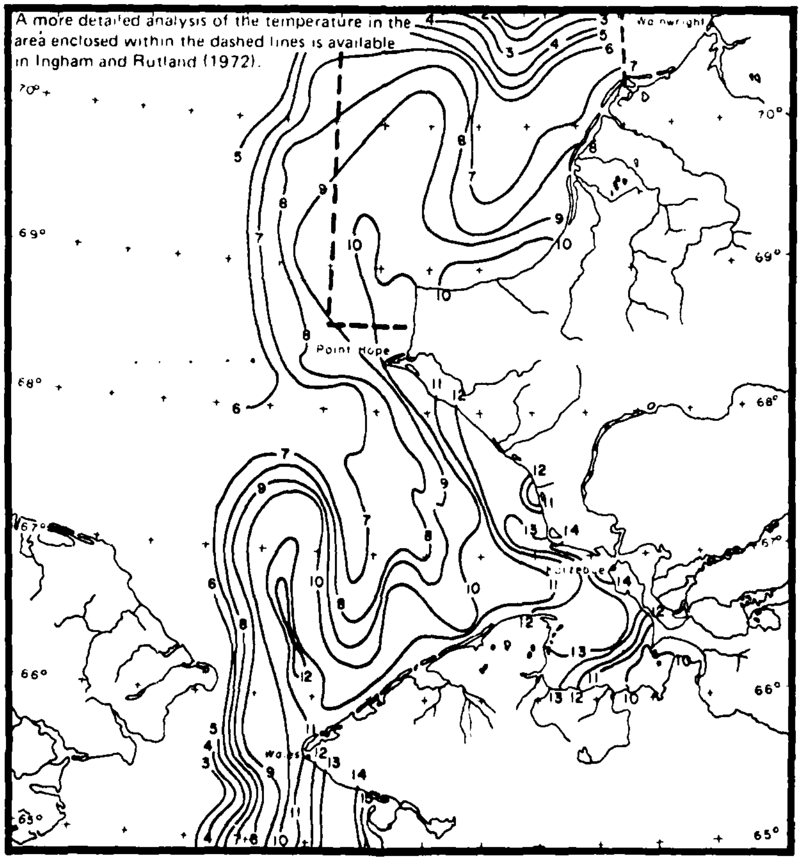


Figure 97. Surface temperatures in ^{o}C.

Figures 97 through 99 illustrate the summer temperature regime during 1959 and 1960. Waters at all depths adjacent to the Alaskan coast are warm (10 to 16°C), whereas those in the western parts of the area are cold (2 to 3°C) at all depths (Fleming and Heggarty 1966). A more detailed analysis of the temperature regime of the northeast Chukchi Sea during fall of 1970, shown outlined in dashed lines on Figure 97, is available in Ingham and Rutland (1972) from Chukchi Sea ref. 12).

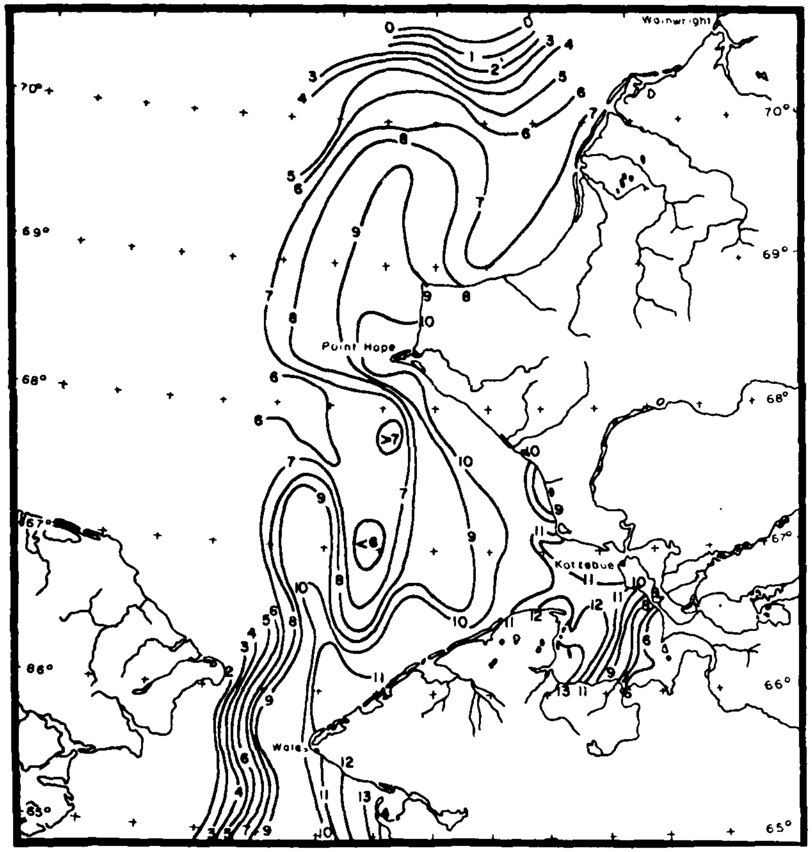


Figure 98. Temperatures in °C at 5 meter depth.

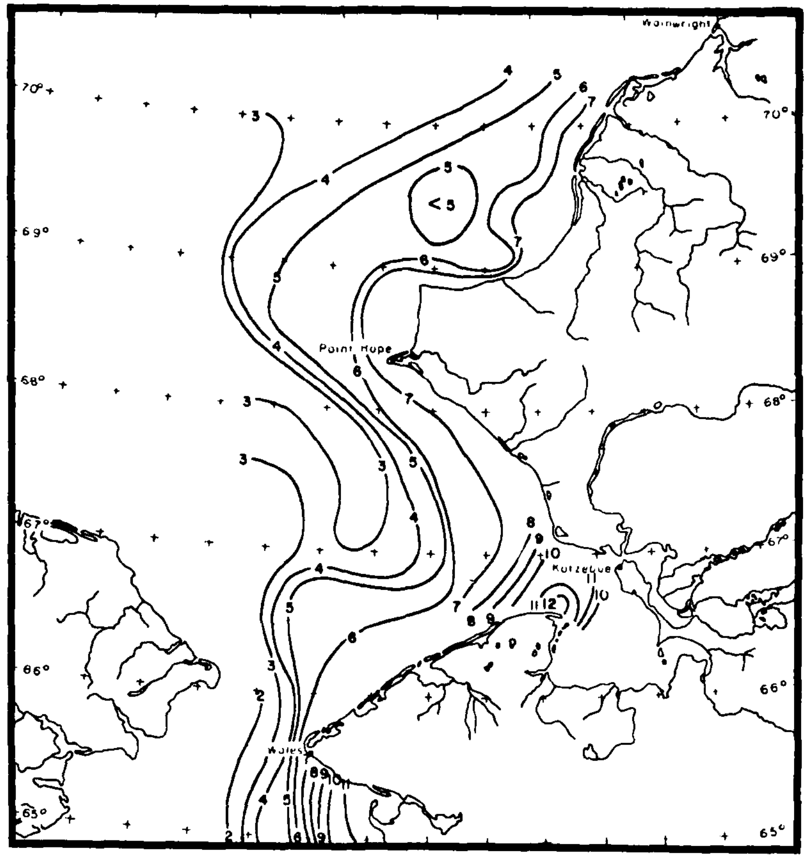


Figure 99. Temperatures in °C at 20 meter depth.

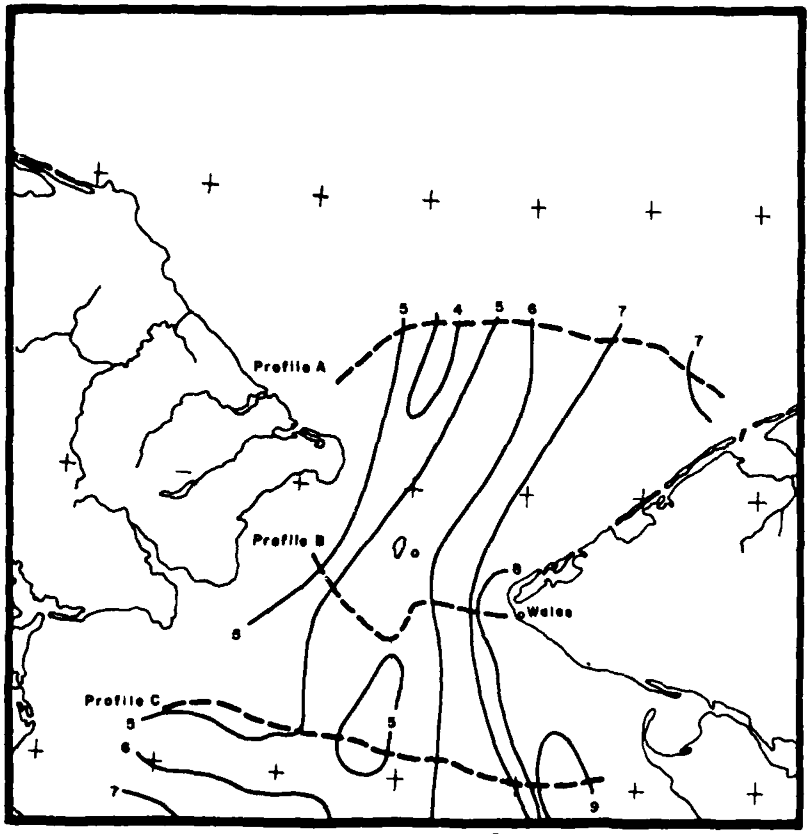


Figure 100. Surface temperatures in $^{\circ}C$. Vertical temperature profiles A, B and C are illustrated in Figures 14 through 16.

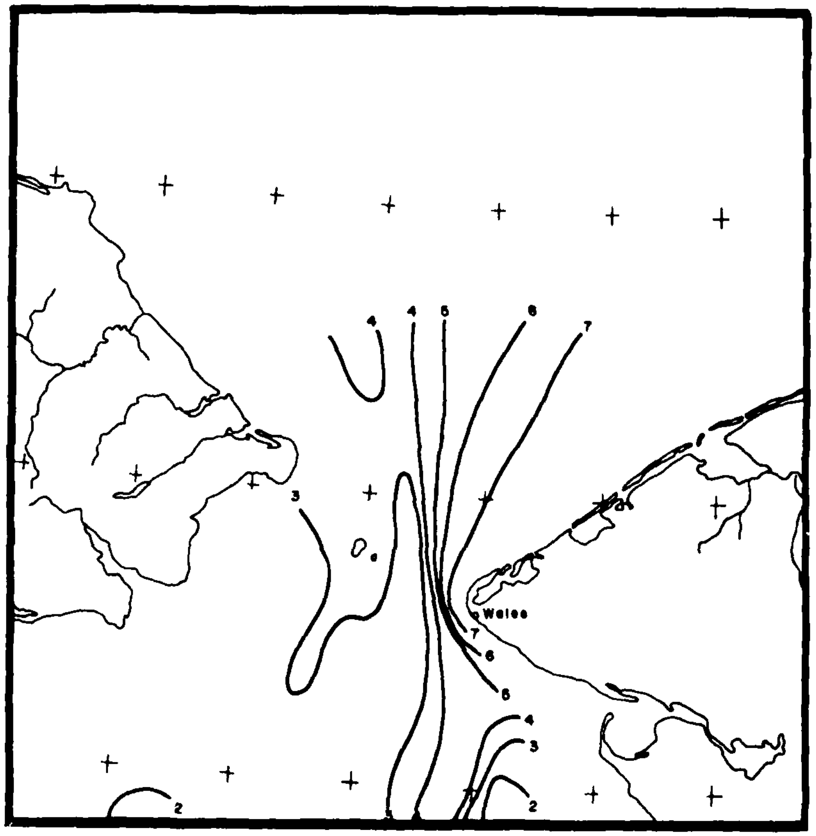


Figure 101. Temperatures in $^{\circ}C$ at 20-meter depth.

Figures 100 and 101 illustrate the temperature regime in Bering Strait in summer 1968 (Husby 1970) (from Chukchi Sea ref. 12).

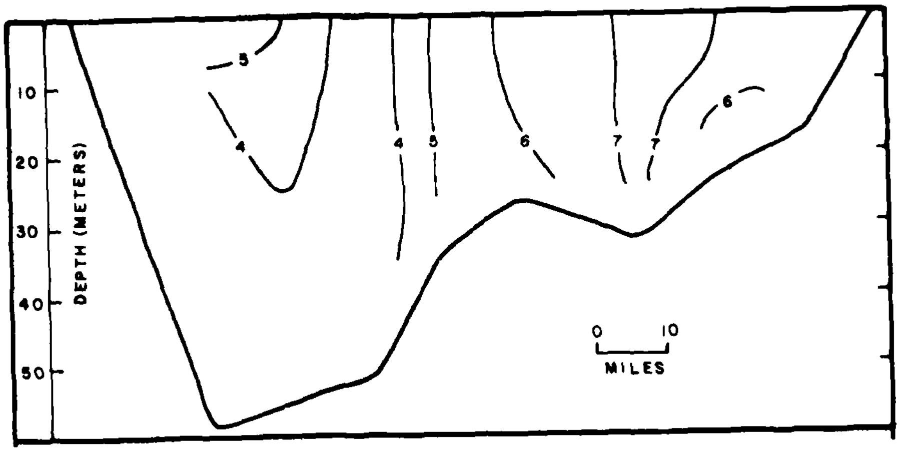


Figure 102. Vertical temperature regime (°C) along Profile A.

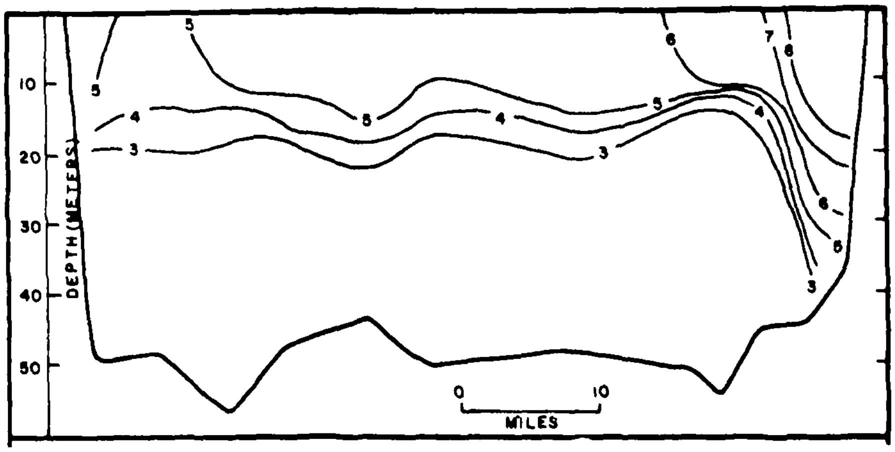


Figure 103. Vertical temperature regime (°C) along Profile B.

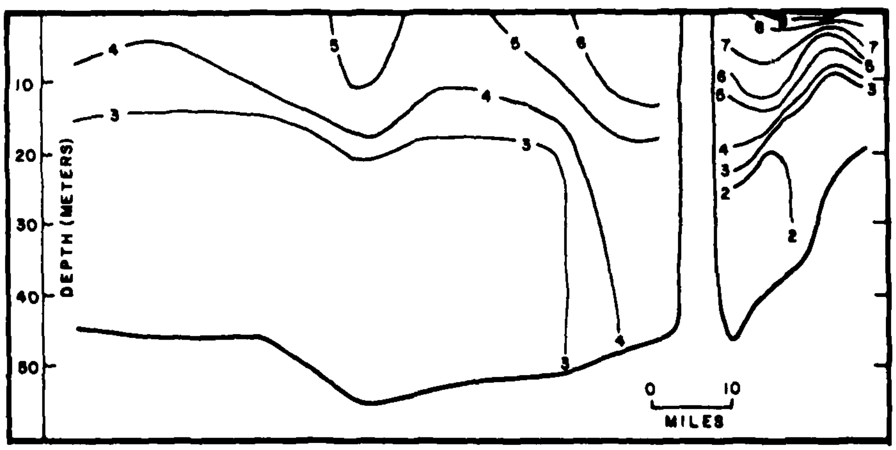


Figure 104. Vertical temperature regime (°C) along Profile C.

Figures 102 through 104 illustrate cross sectional temperature profiles through the Bering Strait area as indicated in dashed lines on Figure 100 (Husby 1970) (from Chukchi Sea ref. 12).

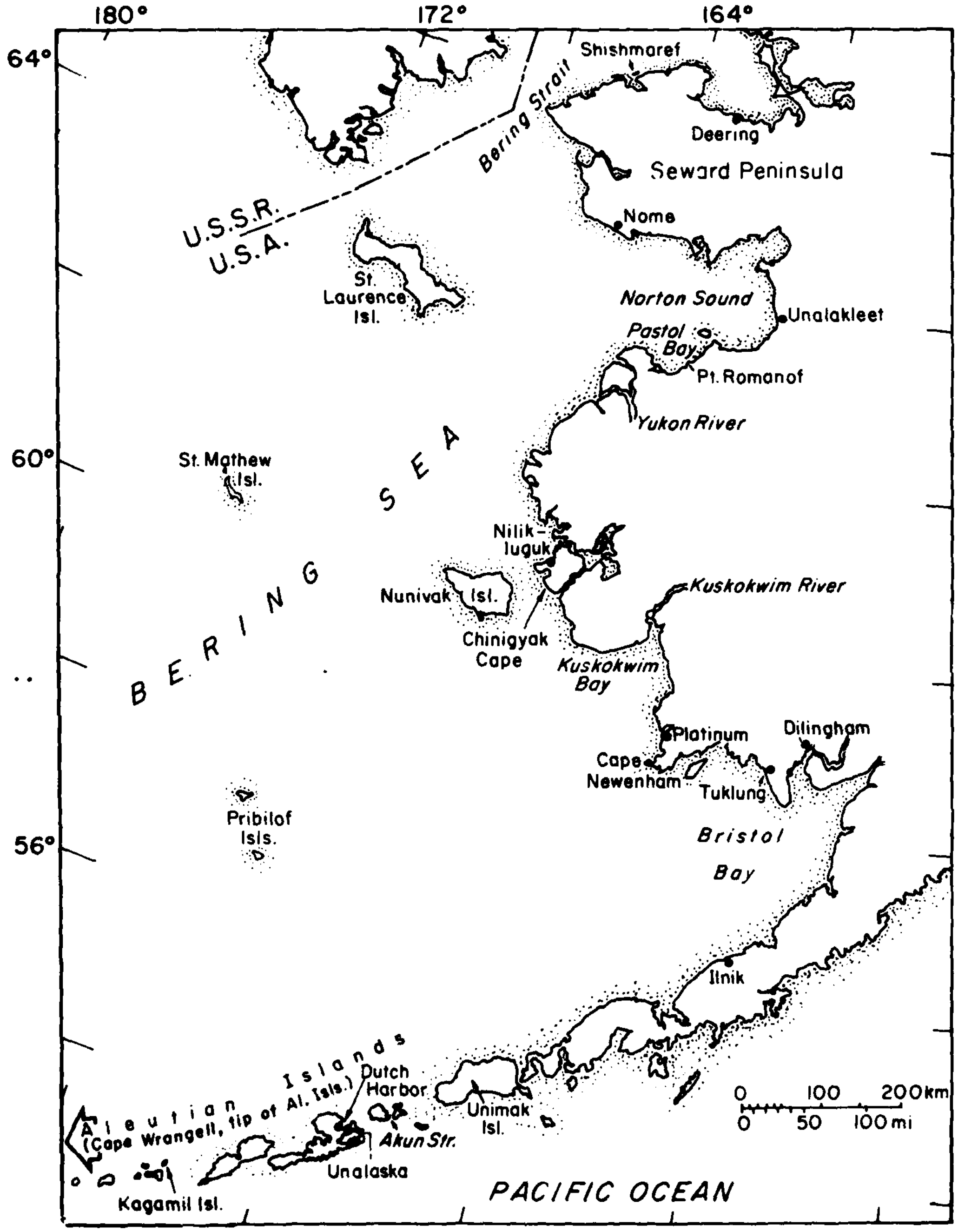


Figure 105. Bering Sea coast from the Bering Strait to the Aleutian Islands.

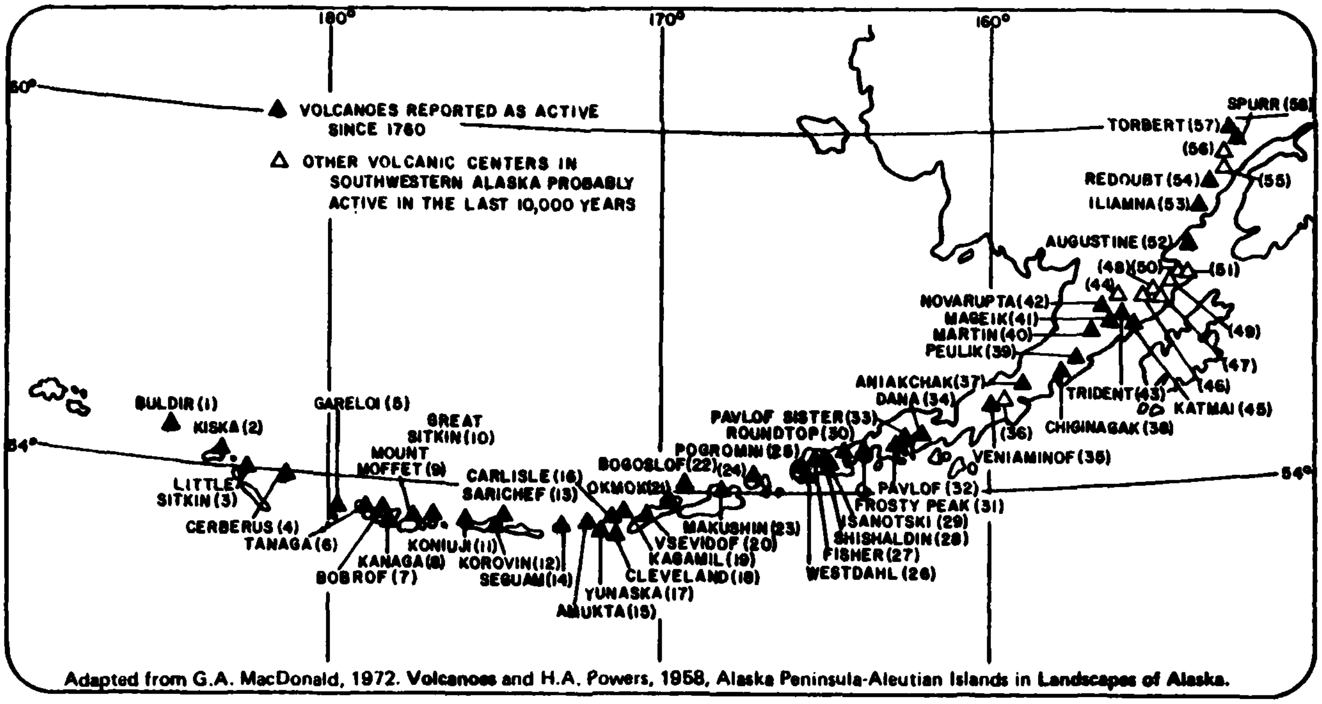


Figure 106. Alaskan volcanoes (from Bering Sea ref. 1).

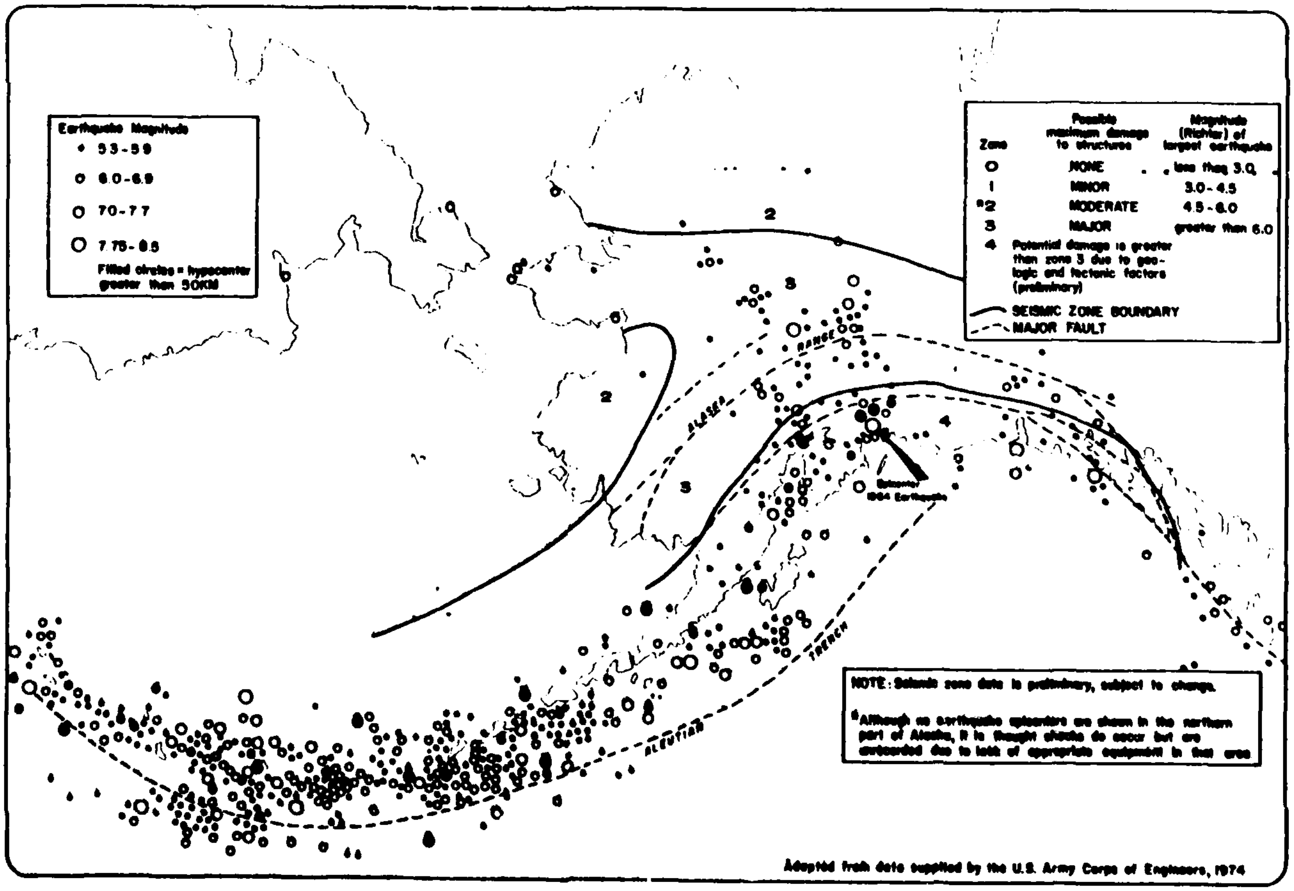


Figure 107. Seismic zone map of Alaska (from Bering Sea ref. 1).

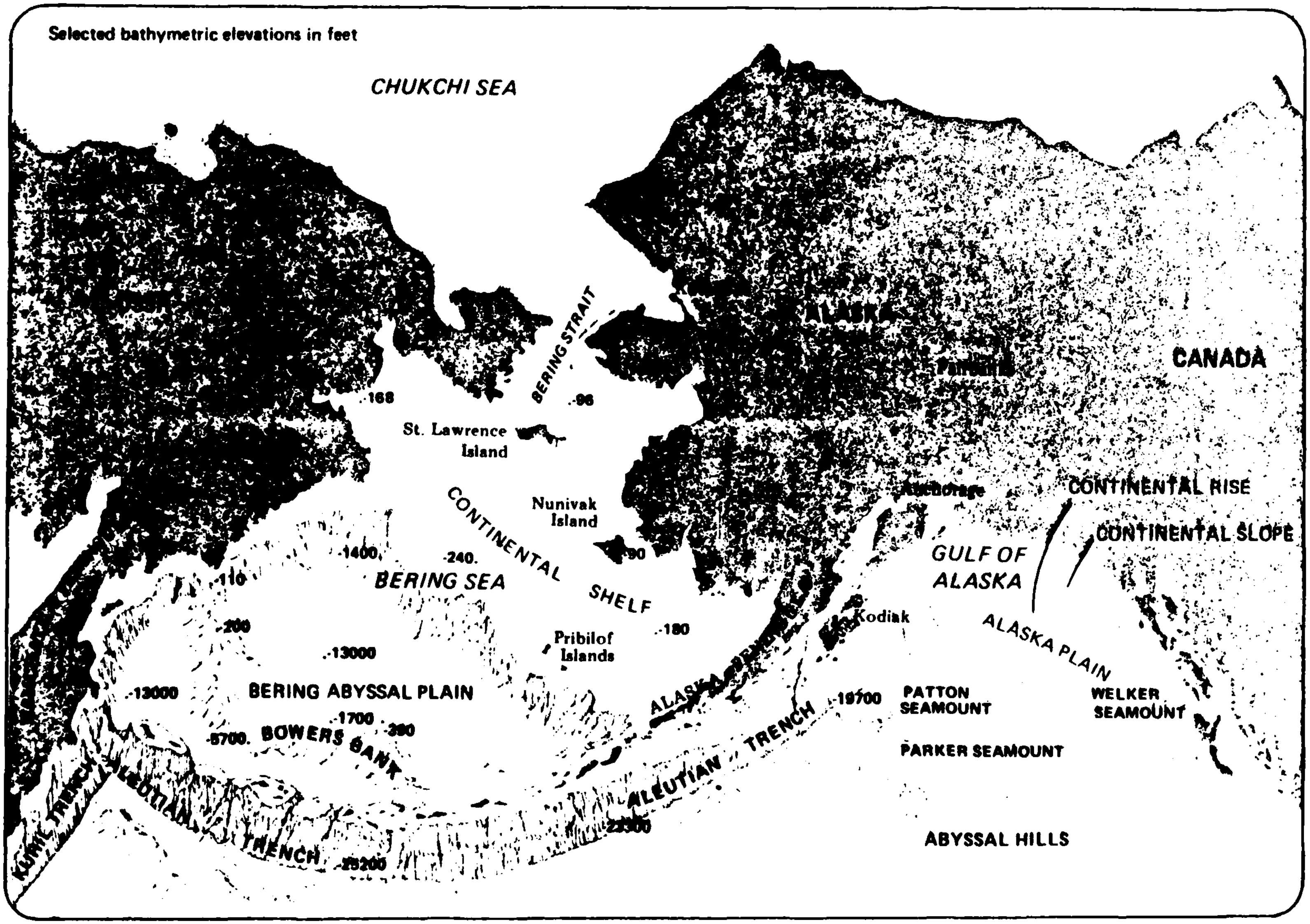


Figure 108. Offshore topography (from Bering Sea ref. 1).

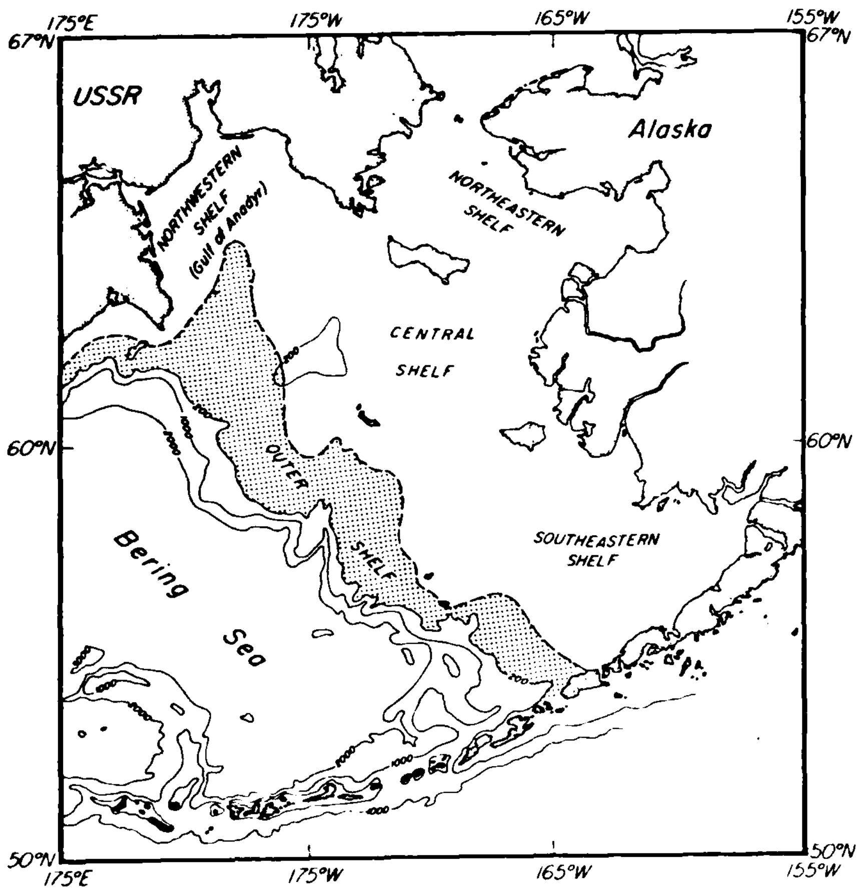


Figure 109. Basinal regimes of the Bering shelf (from Bering Sea ref. 13).

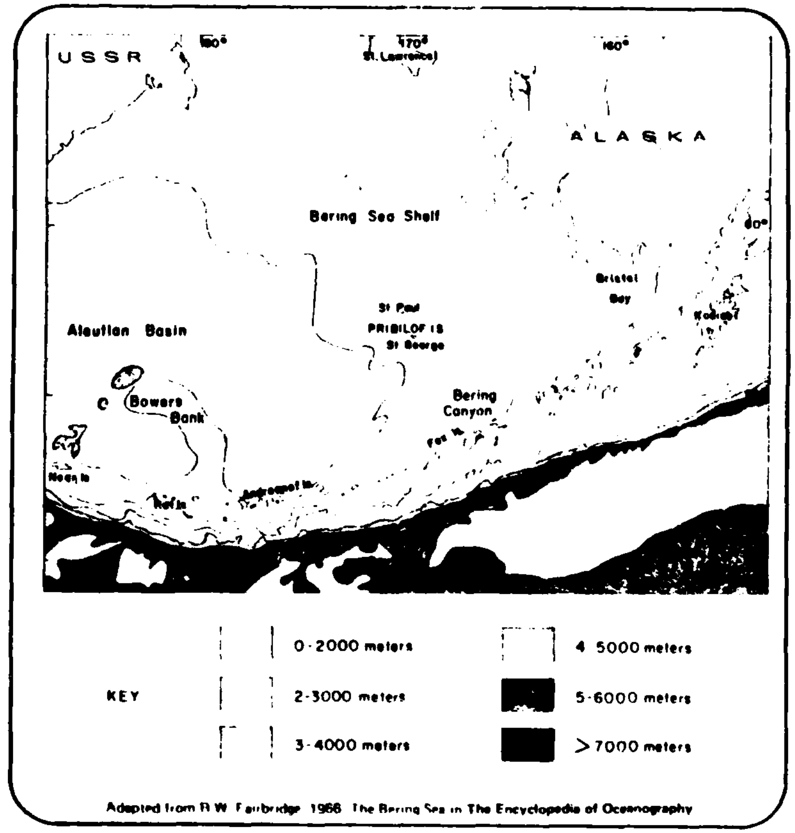


Figure 110. Bathymetry of the Bering Sea (from Bering Sea ref. 1).

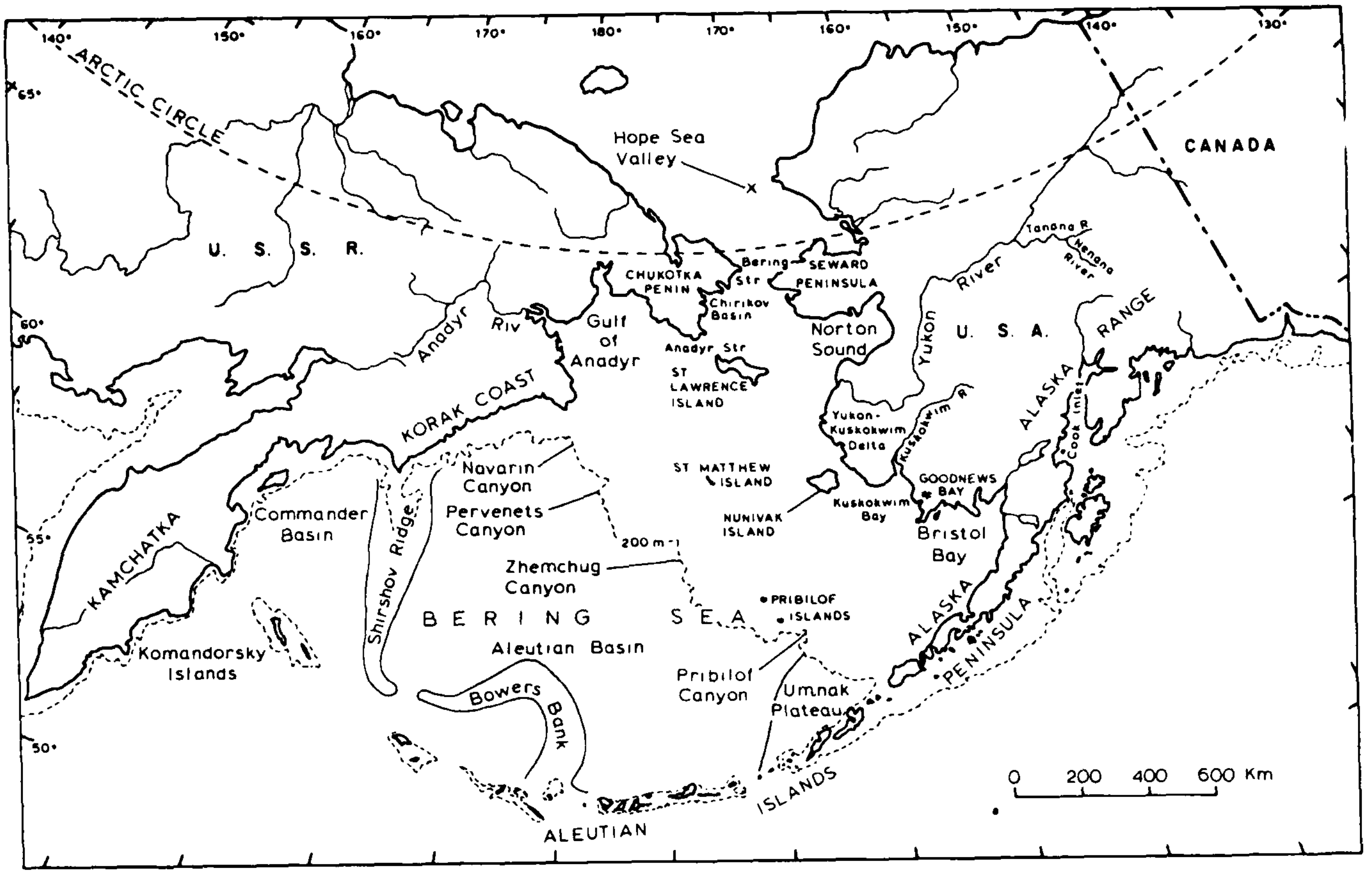


Figure 111. Submarine and continental physiographic features in the Bering Sea region.(from Bering Sea ref. 12).

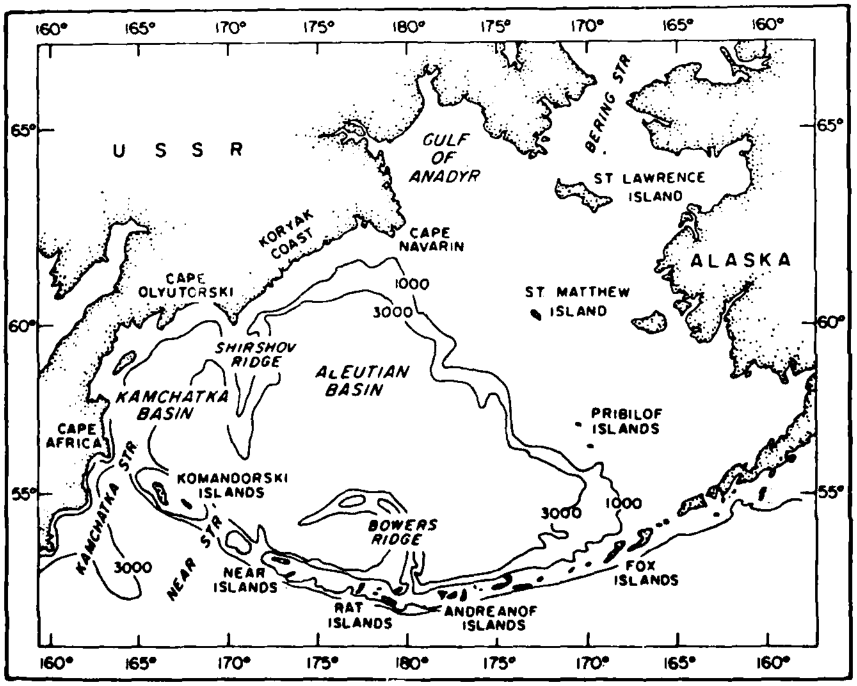


Figure 112. The Bering Sea (depth contours in meters) (from Bering Sea ref. 11).

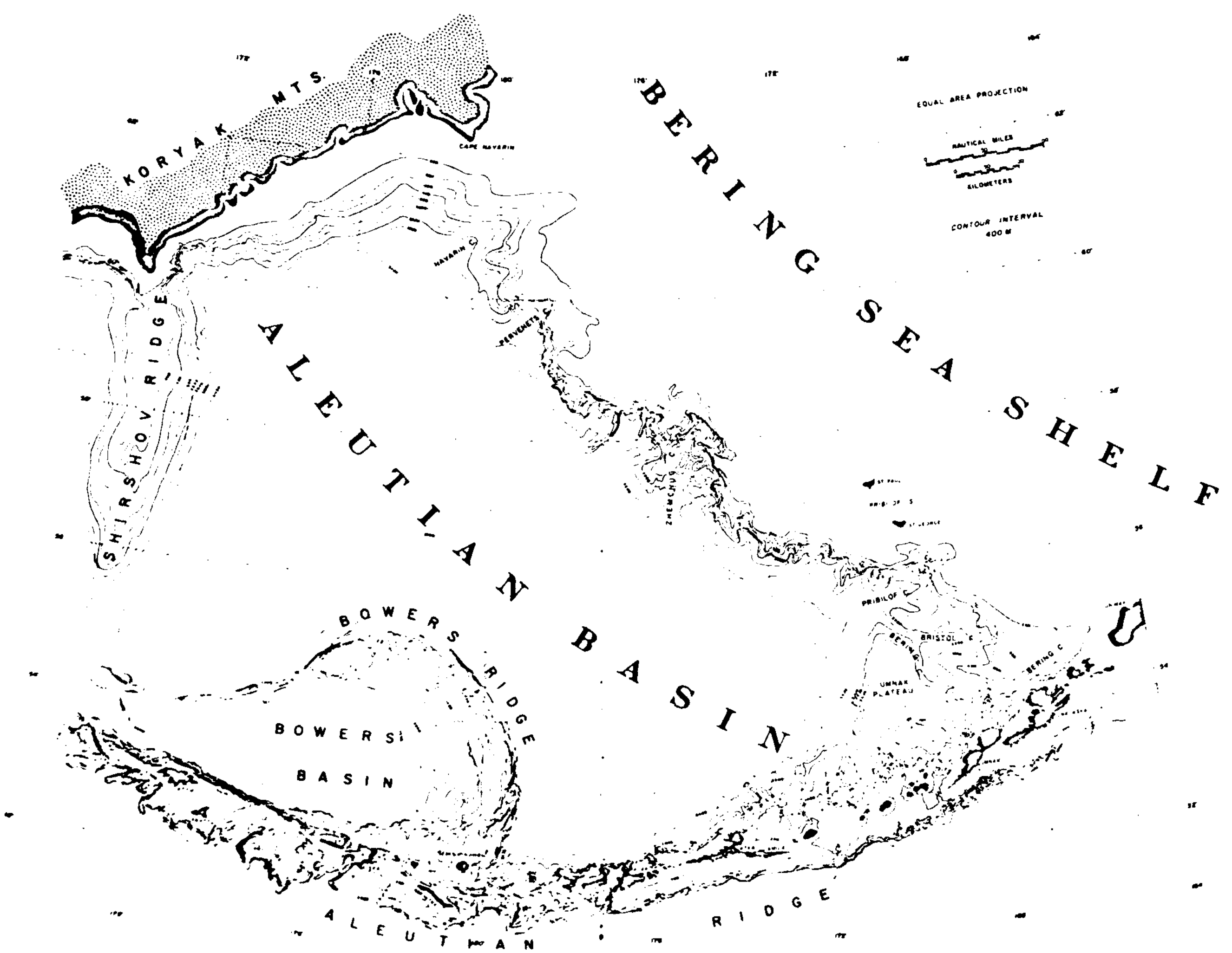


Figure 113. Generalized bathymetric chart of the Aleutian Basin (from Bering Sea ref. 15).

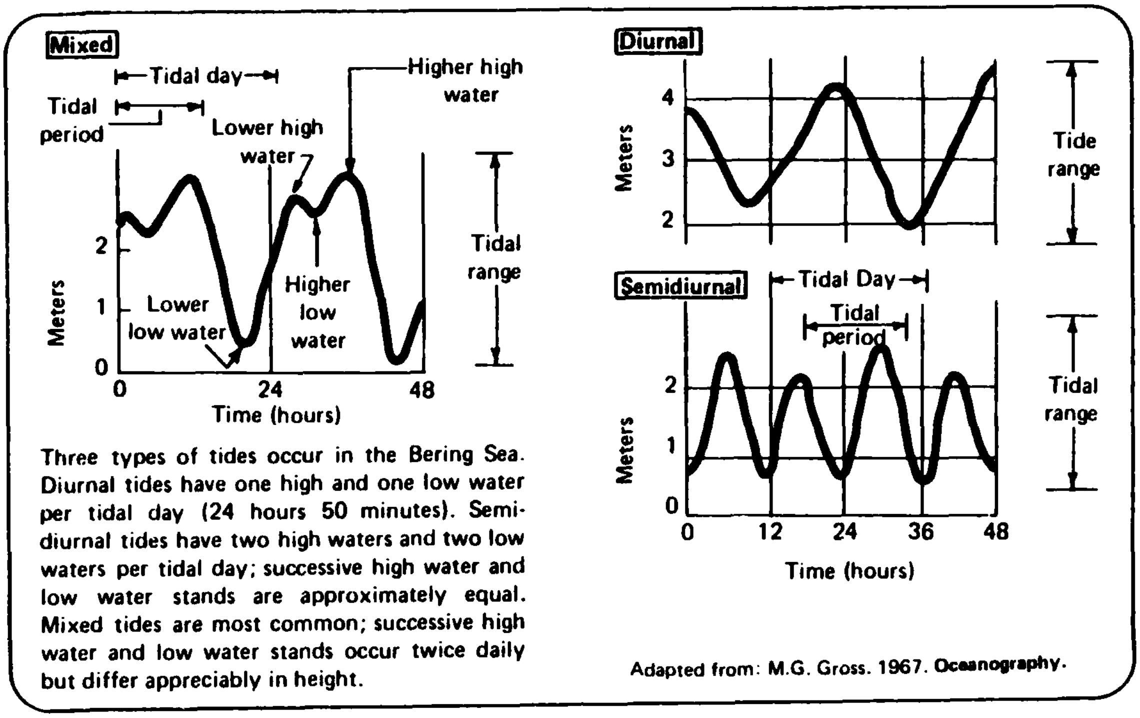


Figure 114. Characteristic features and types of tides (from Bering Sea ref. 1).

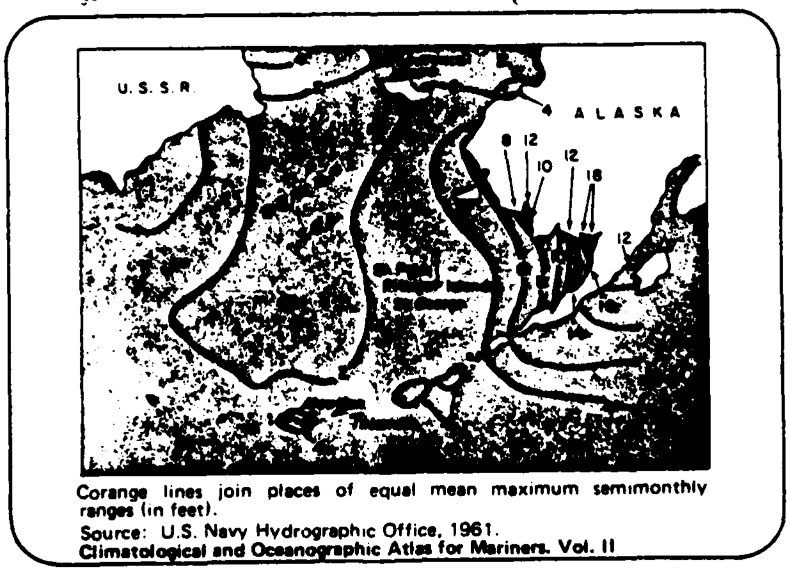
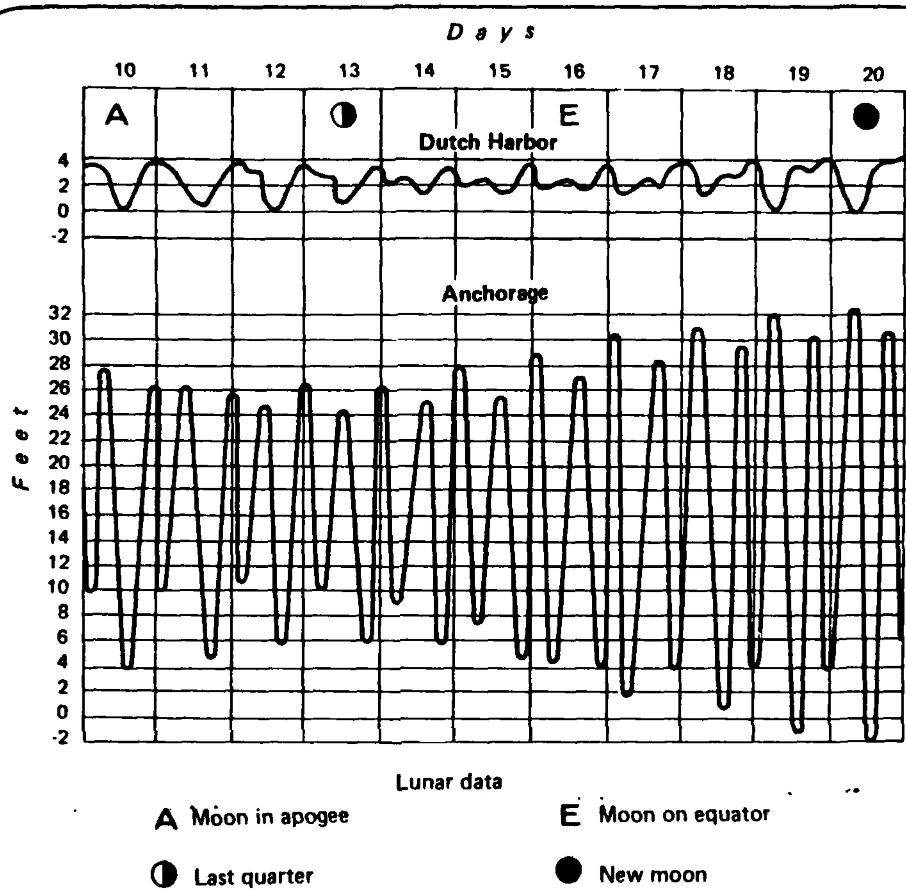


Figure 115. Corange lines for southwest Alaskan seas (from Bering Sea ref. 1).



Note: Tidal variations in northwest Alaska are similar to the tidal cycle at Dutch Harbor. Anchorage data are shown for comparison.

Source: U.S. National Ocean Survey. 1974a. **Tide Tables, West Coast of North and South America, Including the Hawaiian Islands, 1975.**

Figure 116. Tidal variations (from Bering Sea ref. 1).

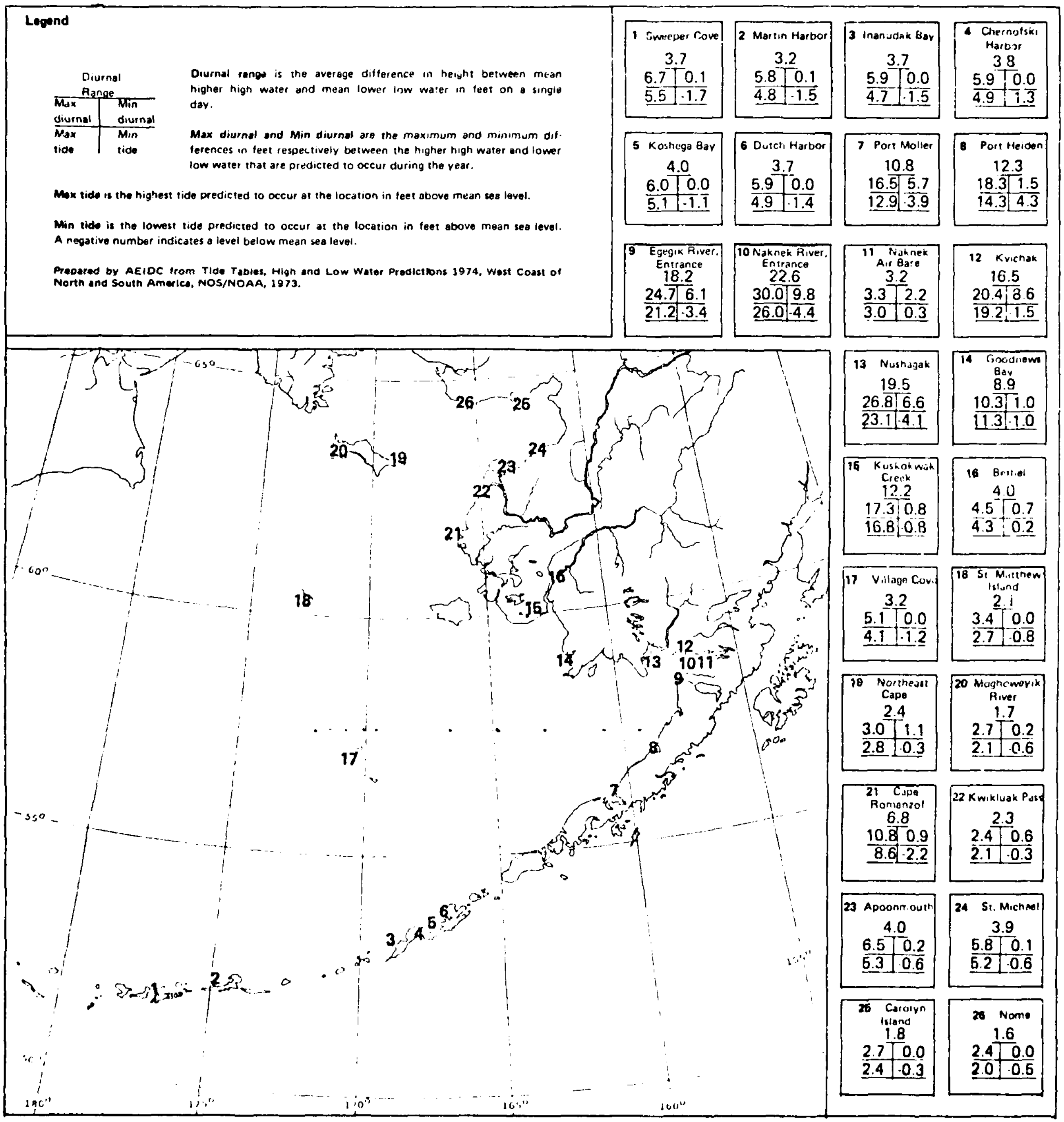


Figure 117. Tide data (from Bering Sea ref. 2).

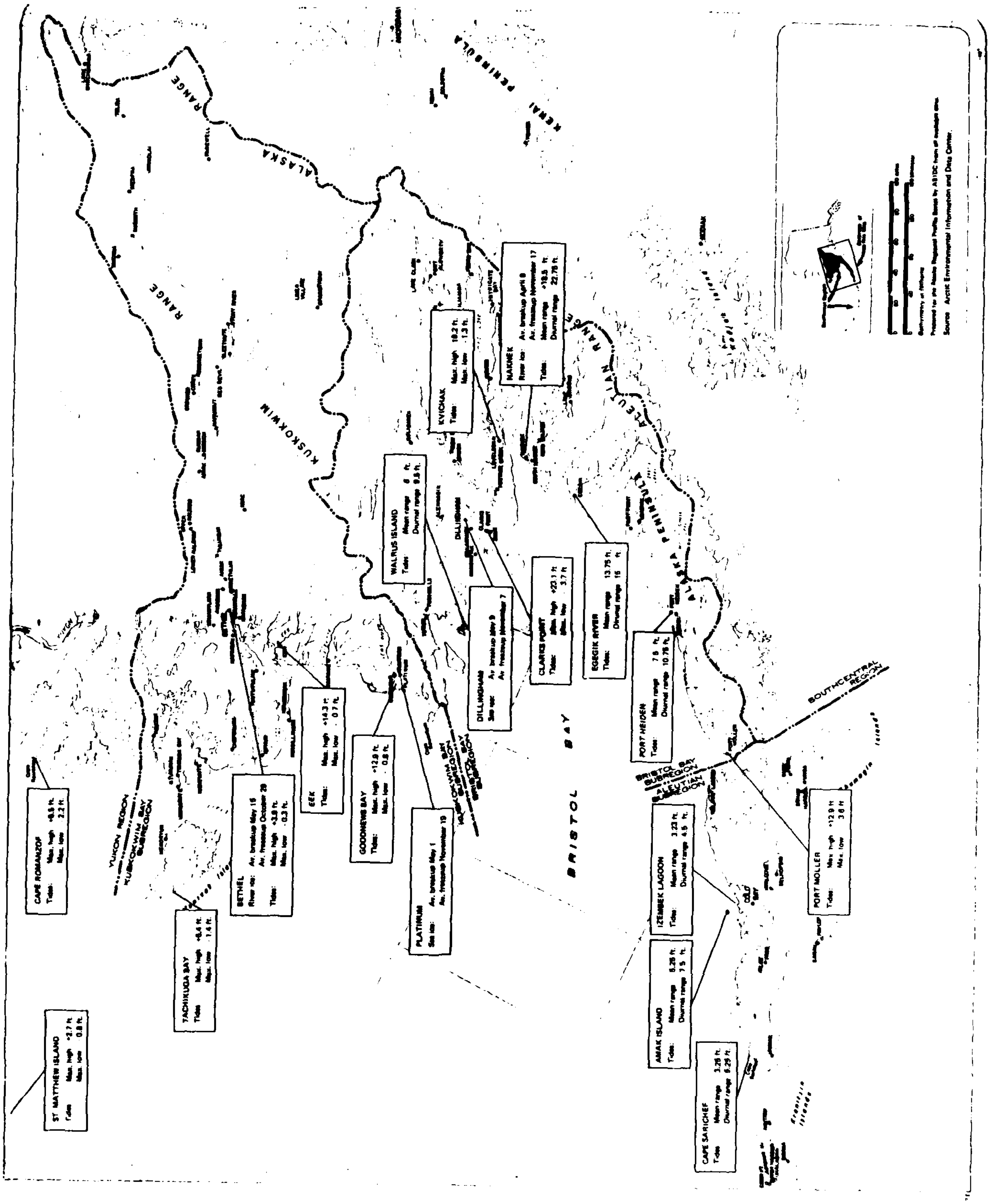


Figure 118. Ice breakup and tides, southwest region (from Bering Sea ref.1).

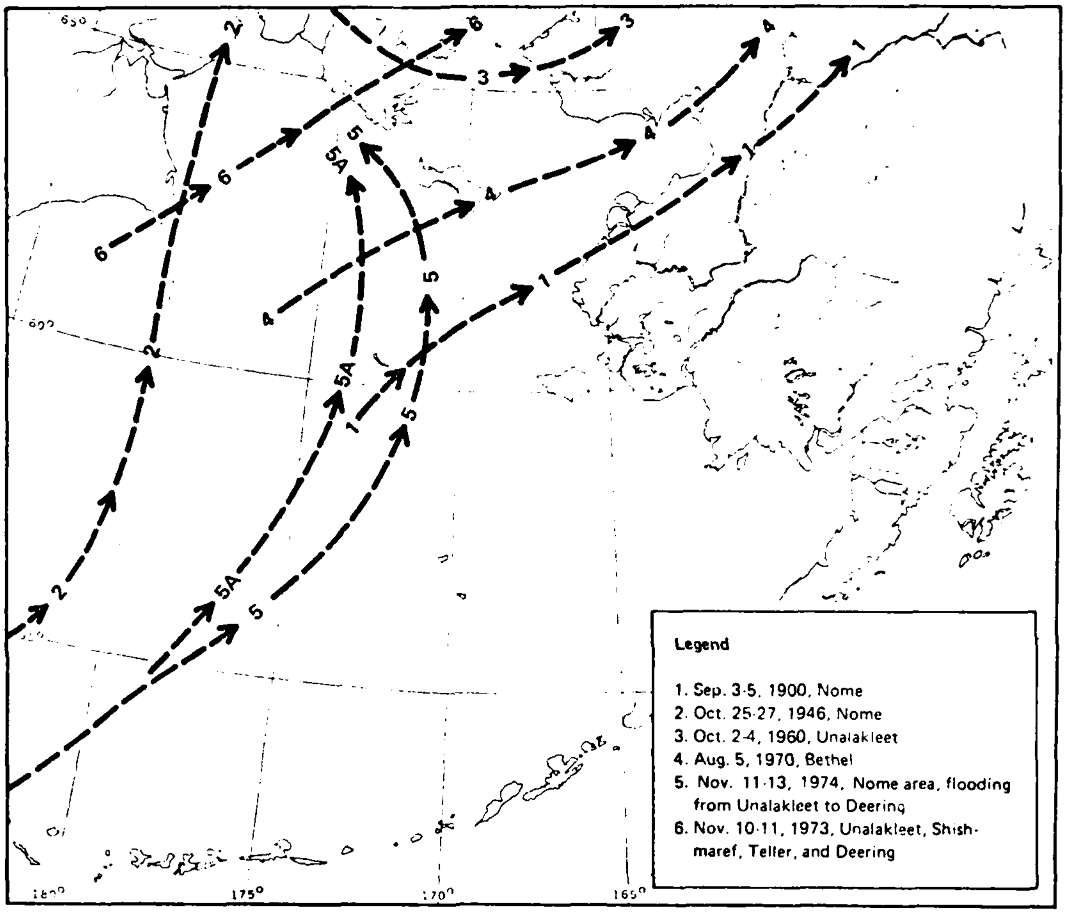


Figure 119. Storm surge occurrences (from Bering Sea ref. 2).

Sea Height (Feet)	Cape Lisburne 0-3	4-10	11-21	22-33	34-47	>48	St. Lawrence Island 0-3	4-10	11-21	22-33	34-47	>48
1	5.3	21.0	0	0	0	0	8.9	21.1	0	0	0	
1-2	1.1	8.0	19.5	0	0	0	0.8	12.1	17.1	0	0	
3-4		3.1	13.4	10.7	0	0	0.3	4.0	11.1	3.7	0	
5-6		0.8	3.4	3.8	0.4	0		0.9	7.1	2.7	0	
7			1.9	3.1	0.4	0		0.3	2.0	1.3	0.1	
8-9			0.4	1.1	0.8	0		0.2	2.1	1.2	0.1	
10-11			0.4	0.4	0.4	0		0	0.4	0.3		
12				0.4		0		0.1	0.7	0.3		
13-16						0			0.2	0.5		
17-19						0.4				0.2		

Wind Speed (knots)

Cape Lisburne — Note: Total Observations = 262
Over period 1963 to 1969

St. Lawrence Island — Note: Total observations = 996
Over period 1963 to 1970

Adapted from U.S. Naval Weather Service Command, 1970. **Summary of Synoptic Meteorological Observations, North American Coastal Marine Areas. Volume 15.**

Figure 120. Frequency of occurrence of sea height as a function of wind speed (from Bering Sea ref. 1).

Location and State	Percentage of Frequency Winter	Spring	Summer	Autumn
Cape Douglas to Unimak Island				
Seas equal or greater than 5 ft.	10-25%	2-10%	5-10%	20-35%
Seas equal or greater than 8 ft.	5-10%	2- 7%	2- 5%	5-15%
Seas equal or greater than 12 ft.	2- 5%	2%	2%	5-10%
Aleutian Chain				
Seas equal or greater than 5 ft.	10-30%	2-20%	5-10%	20-40%
Seas equal or greater than 8 ft.	5-10%	2-10%	5%	5-20%
Seas equal or greater than 12 ft.	2-10%	2-10%	2- 5%	5-20%

David M. Hickok, 1972. "Understanding the Alaska Coastal Zone." Unpublished manuscript prepared for the State of Alaska C.O.A.S.T. Commission.

Figure 121. Waves in the Bering Sea (from Bering Sea ref. 1).

Legend

Annual maximum winds and waves for selected return periods—Marine areas

Return periods for maximum sustained winds and for maximum significant and extreme wave heights are presented in tabular form for selected marine areas. Sustained winds are winds averaged over a period of one minute, the significant wave height is the average height of the highest one third of all waves (sea and swell) in view, and the extreme wave height is an empirical estimate of 1.8 times the significant wave height. Estimates presented in the tables were based primarily on methods described by Thom (see References). For example, on the average the Marine Area A can expect annual maximum sustained wind speed to exceed 110 knots once in 100 years.

Area B

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	75	13.5 (44)	24.0 (78)
10	81	15.0 (49)	27.0 (89)
25	91	17.5 (58)	31.5 (104)
50	98	20.0 (65)	35.5 (117)
100	107	22.5 (73)	40.0 (131)

Area C

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	75	13.0 (43)	24.0 (78)
10	81	15.0 (49)	27.0 (89)
25	90	17.5 (58)	31.5 (104)
50	98	20.0 (65)	35.5 (117)
100	106	22.5 (73)	40.0 (131)

Area D

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	74	13.0 (43)	24.0 (78)
10	81	15.0 (49)	27.0 (88)
25	90	17.5 (57)	31.5 (103)
50	98	20.0 (65)	35.5 (116)
100	106	22.5 (73)	40.0 (131)

Area A

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	78	13.5 (45)	24.5 (81)
10	84	15.5 (51)	28.0 (92)
25	94	18.5 (60)	33.0 (108)
50	102	20.5 (67)	36.0 (121)
100	110	23.0 (76)	42.5 (136)

Area E

Return period years	Maximum sustained wind-knots	Maximum significant wave-meters (feet)	Extreme wave-meters (feet)
5	74	13.0 (43)	23.5 (77)
10	80	14.5 (48)	26.5 (87)
25	89	17.5 (57)	31.0 (102)
50	97	19.5 (64)	35.0 (115)
100	105	22.0 (72)	39.5 (129)

Figure 122. Annual maximum winds and waves for selected return periods-Marine areas (from Bering Sea ref. 1).

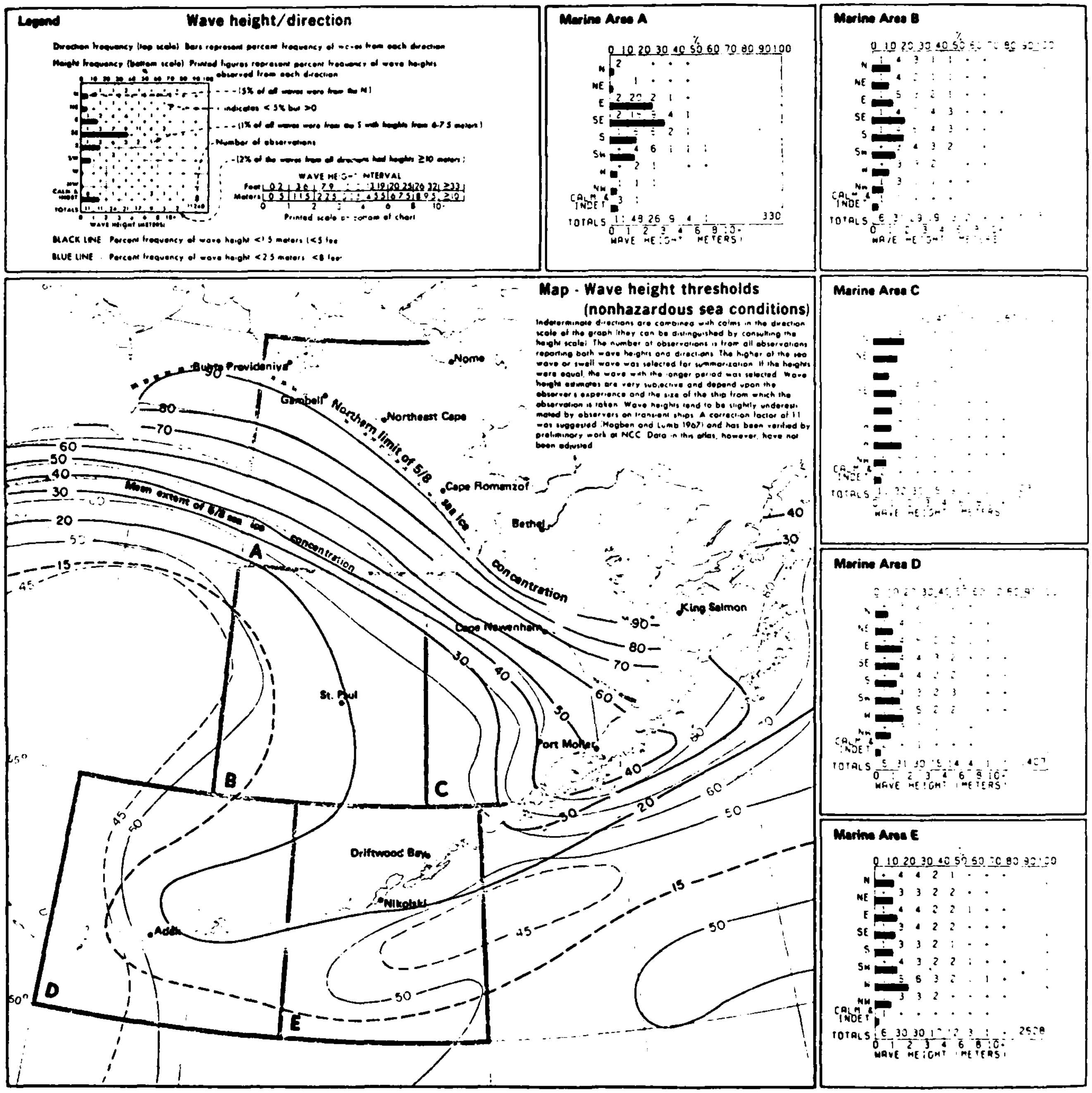
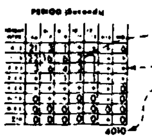


Figure 123. Wave height thresholds (nonhazardous), January (from Bering Sea ref. 2).

Legend

Wave height/period



Percent frequency of occurrence of wave period and height

(2% of observed waves had a height of 1-1.5 meters and a period of 10-11 seconds.)

• indicates < .5% but >0

Number of observations

Waves are selected on the basis of the higher of sea and swell when both are reported. If both heights are equal, the wave with the longer period is selected.

BLACK LINE - Percent frequency of wave height ≥3.5 meters (≥12 feet)

BLUE LINE - Percent frequency of wave height ≥6 meters (≥20 feet)

BLUE NUMBER - Maximum observed wave height (meters)

Marine Area A

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	6	4	1	0	0	0	4
1-1.5	9	24	11	1	•	0	1
2-2.5	9	8	5	1	0	1	1
3-3.5	4	2	2	1	•	0	0
4-5.5	1	1	1	•	0	0	•
6-7.5	0	0	•	•	0	•	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

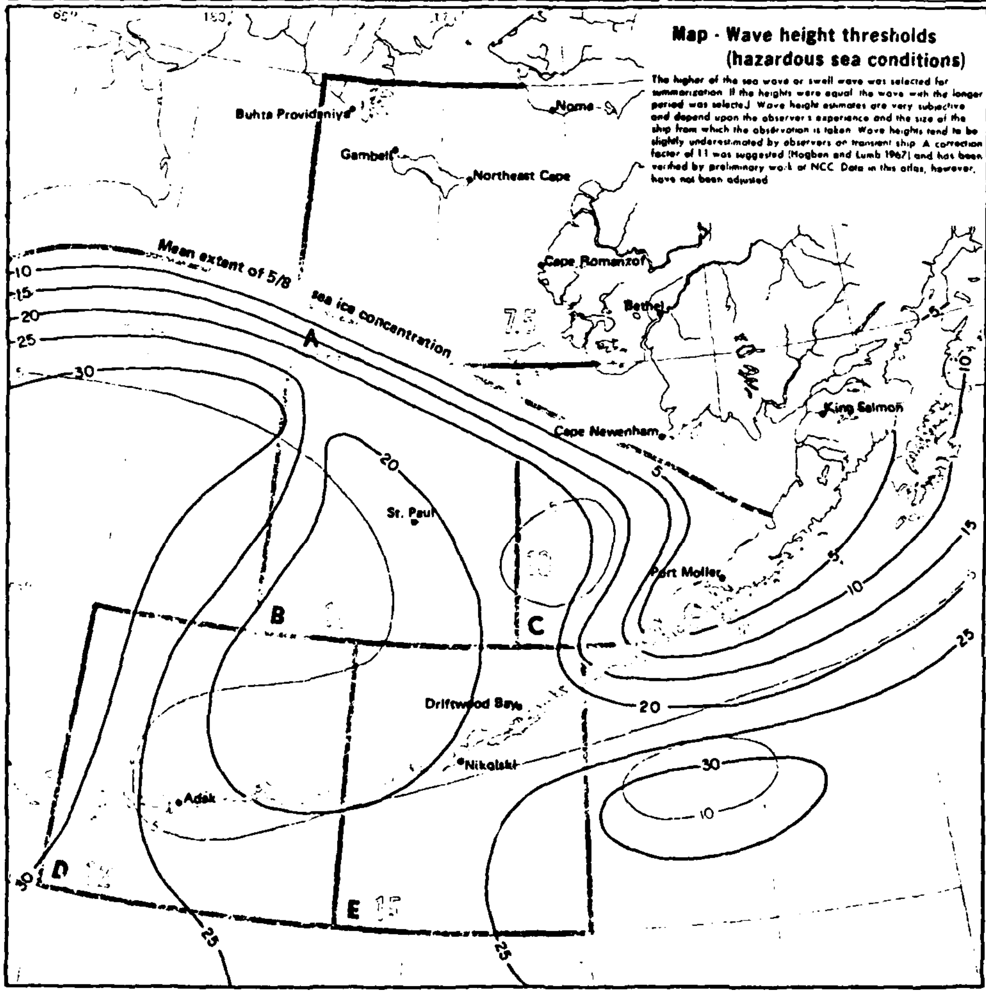
343

Marine Area B

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	4	1	•	•	0	0	2
1-1.5	13	8	4	2	•	•	3
2-2.5	6	12	5	3	1	•	2
3-3.5	1	8	5	1	1	•	2
4-5.5	•	4	5	1	•	•	2
6-7.5	0	•	1	1	•	•	•
8-9.5	0	•	•	0	•	•	•
≥10	0	0	•	0	0	0	0

3147



Marine Area C

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	8	•	[illegible]	•	0	0	3
1-1.5	20	6	2	•	1	•	2
2-2.5	15	10	3	•	•	•	2
3-3.5	2	10	2	•	•	0	1
4-5.5	•	3	4	1	•	0	1
6-7.5	0	0	1	1	•	•	0
8-9.5	0	0	•	•	•	1	0
≥10	0	0	0	•	•	0	0

2365

Marine Area D

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	3	•	•	•	0	0	2
1-1.5	13	10	3	1	1	•	2
2-2.5	5	9	9	3	1	•	2
3-3.5	1	3	5	3	1	•	1
4-5.5	1	2	5	2	2	1	1
6-7.5	0	1	1	1	•	1	•
8-9.5	0	0	•	•	•	•	0
≥10	0	0	•	•	•	•	0

1428

Marine Area E

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	4	•	•	•	0	0	2
1-1.5	13	10	3	2	•	•	2
2-2.5	5	10	8	3	1	•	1
3-3.5	2	5	6	3	1	•	1
4-5.5	•	4	4	3	1	•	•
6-7.5	0	1	1	1	•	1	•
8-9.5	0	•	•	•	•	•	•
≥10	0	0	•	•	•	•	0

2644

Figure 124. Wave height thresholds (hazardous), January (from Bering Sea ref. 2).

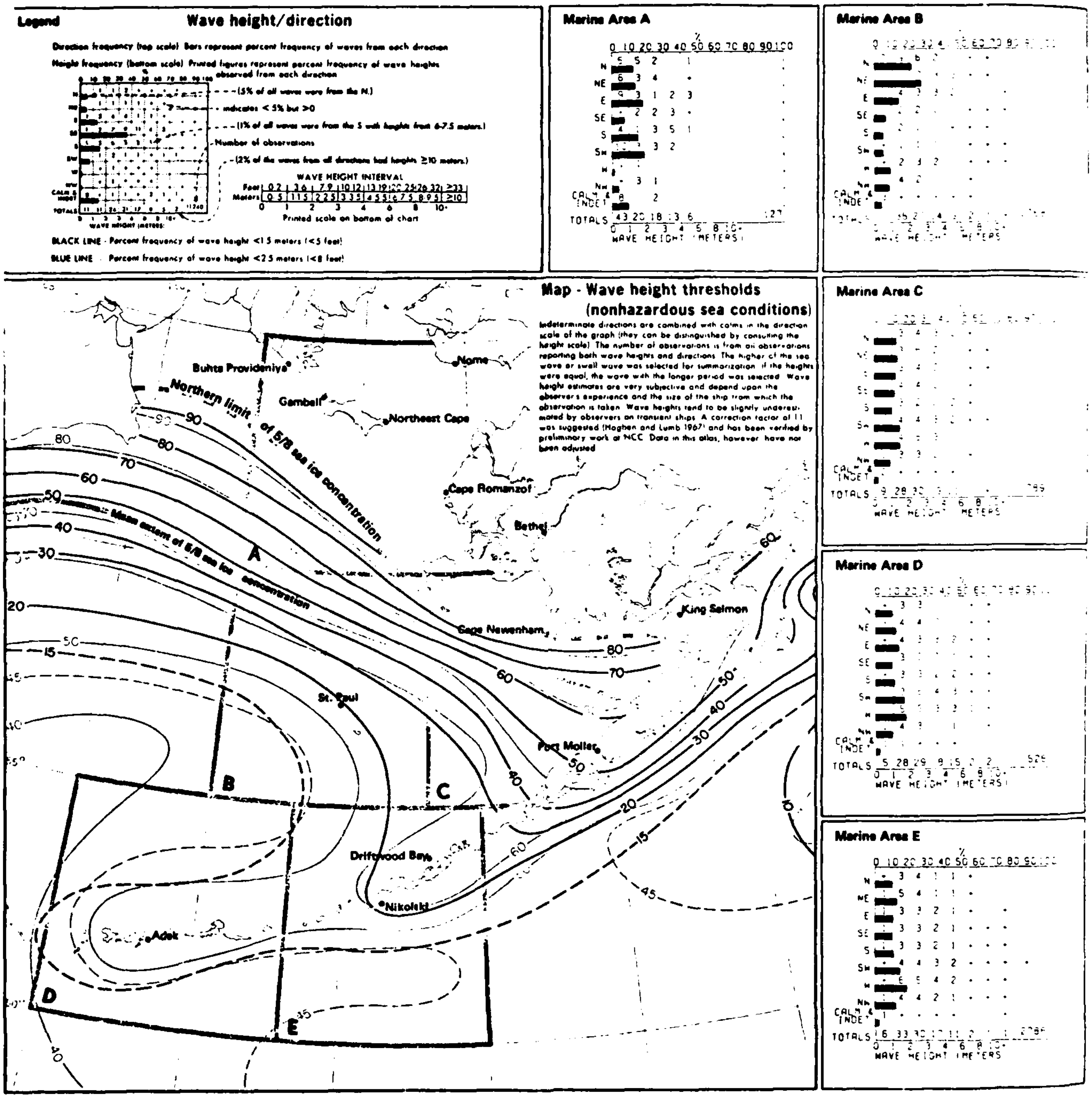


Figure 125. Wave height thresholds (nonhazardous), February (from Bering Sea ref. 2).

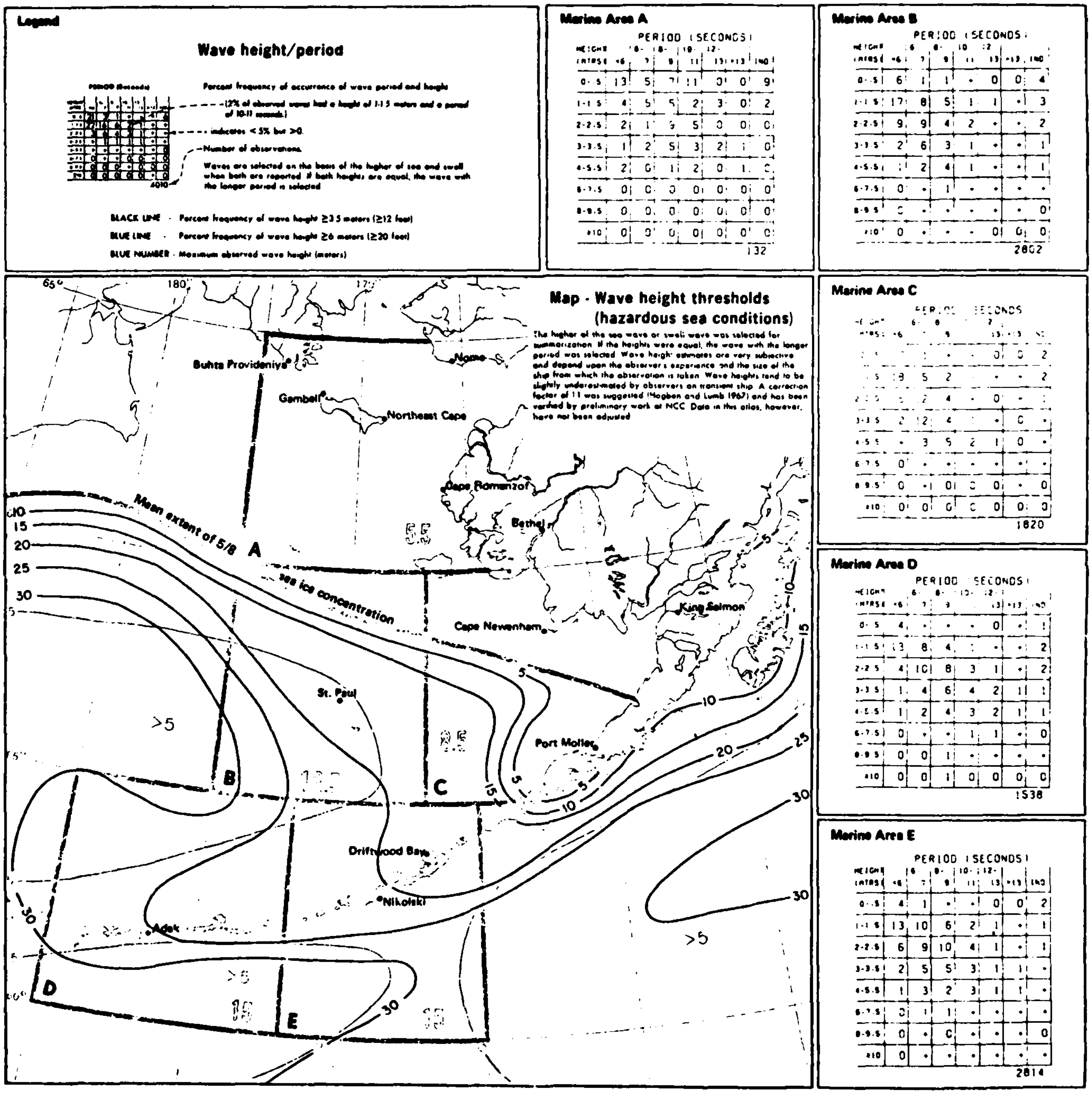


Figure 126. Wave height thresholds (hazardous), February (from Bering Sea ref. 2).

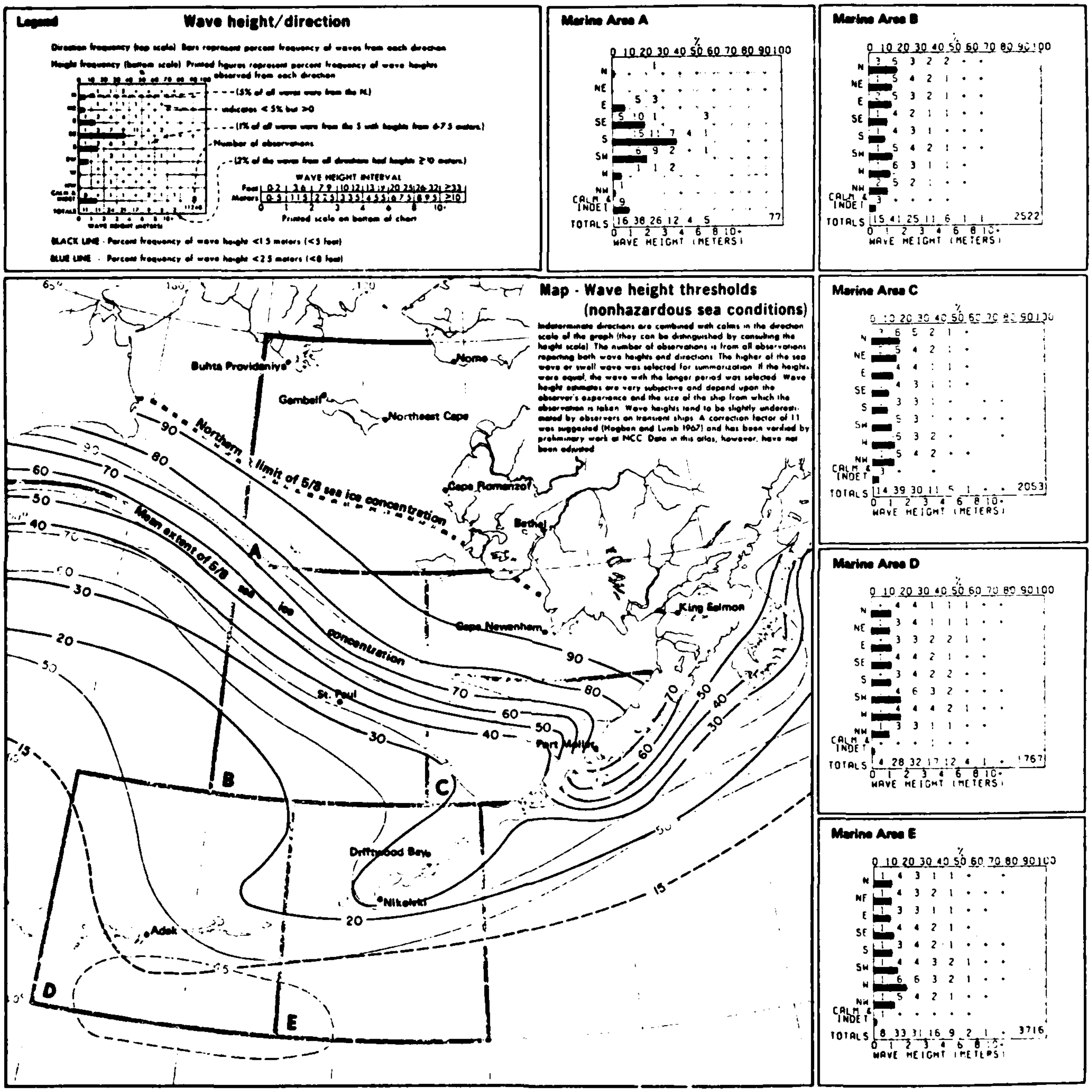


Figure 127. Wave height thresholds (nonhazardous), March (from Bering Sea ref. 2).

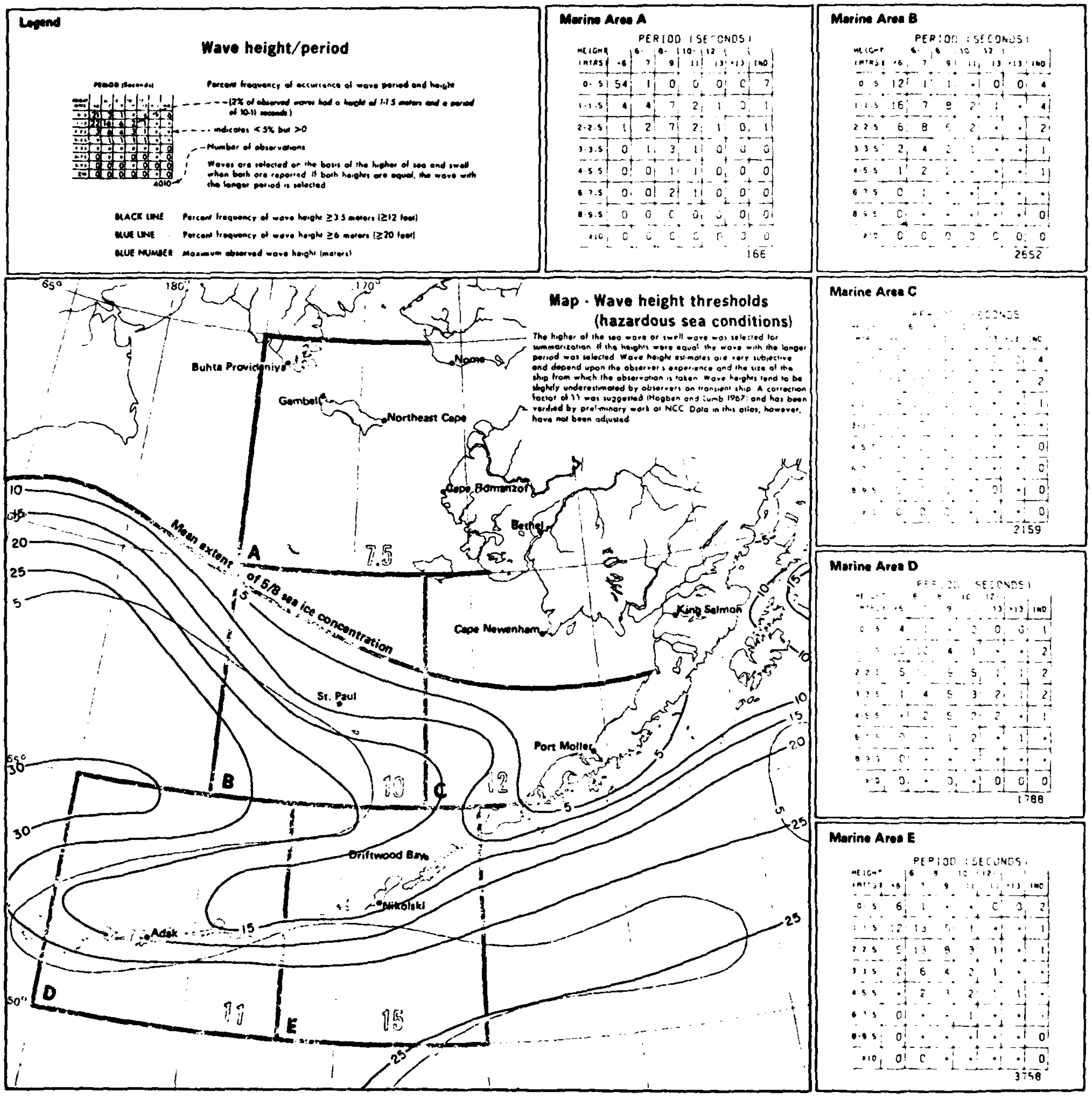


Figure 128. Wave height thresholds (hazardous), March (from Bering Sea ref. 2).

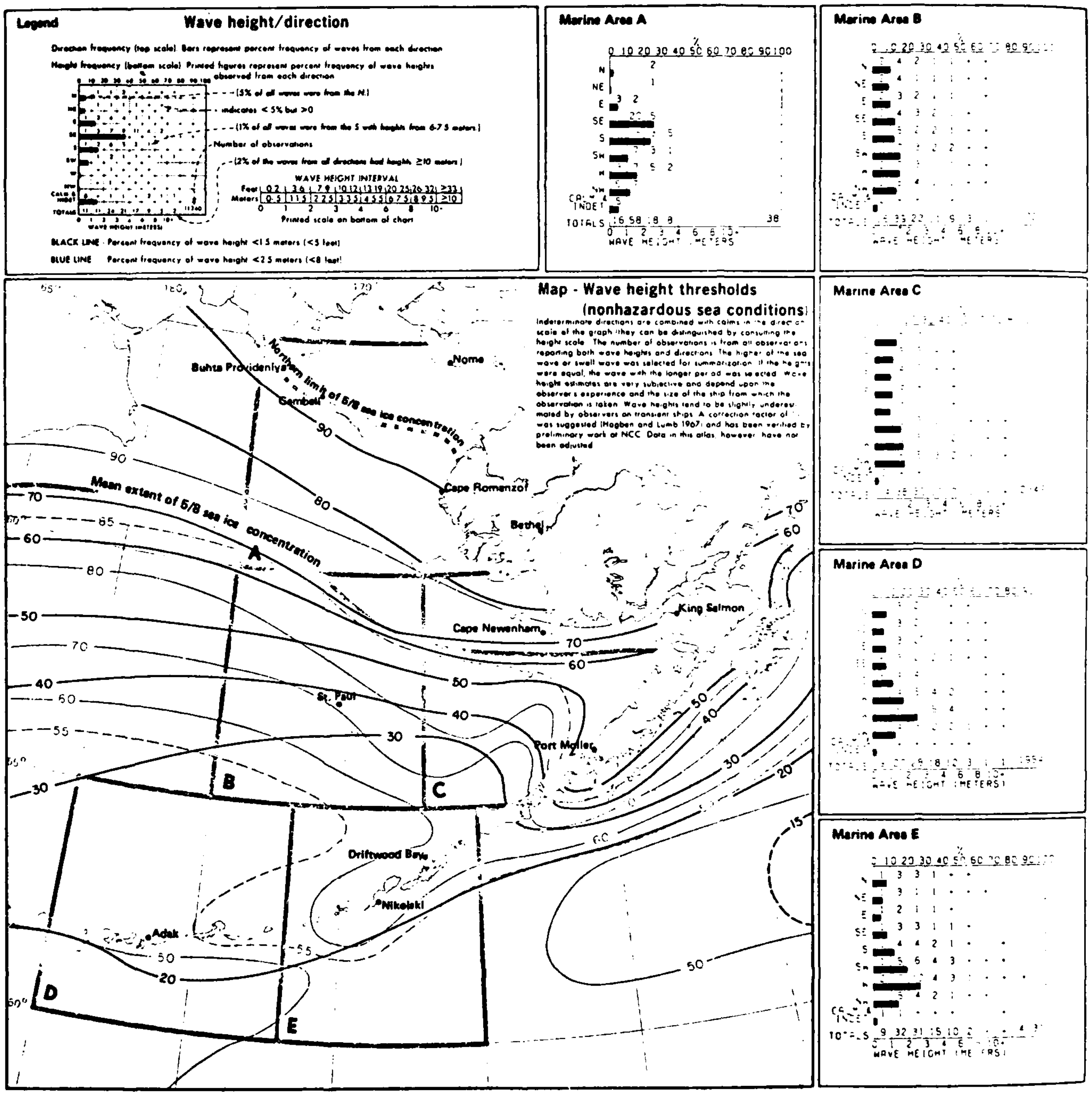


Figure 129. Wave height thresholds (nonhazardous), April (from Bering Sea ref. 2).

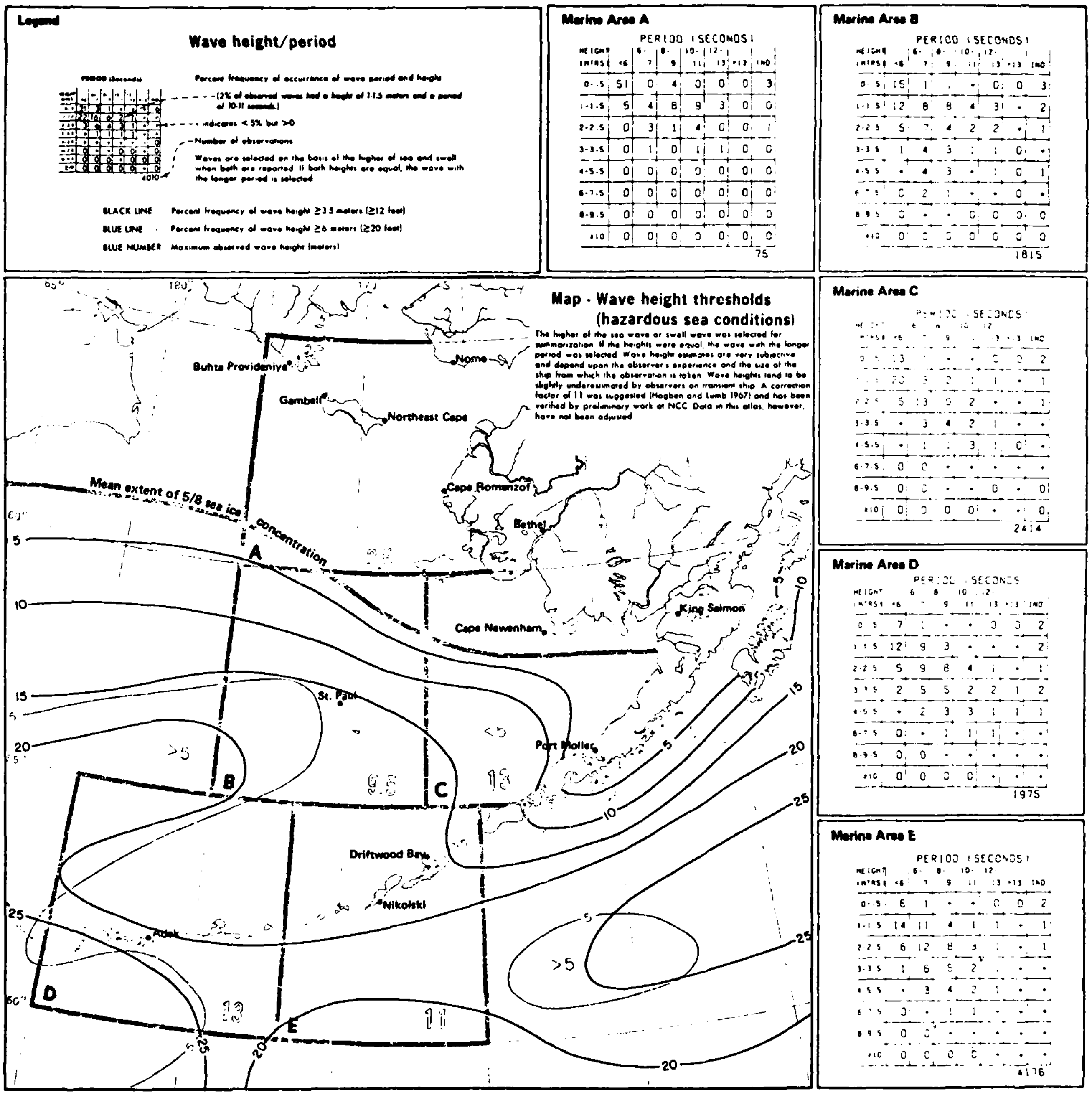


Figure 130. Wave height thresholds (hazardous), April (from Bering Sea ref. 2).

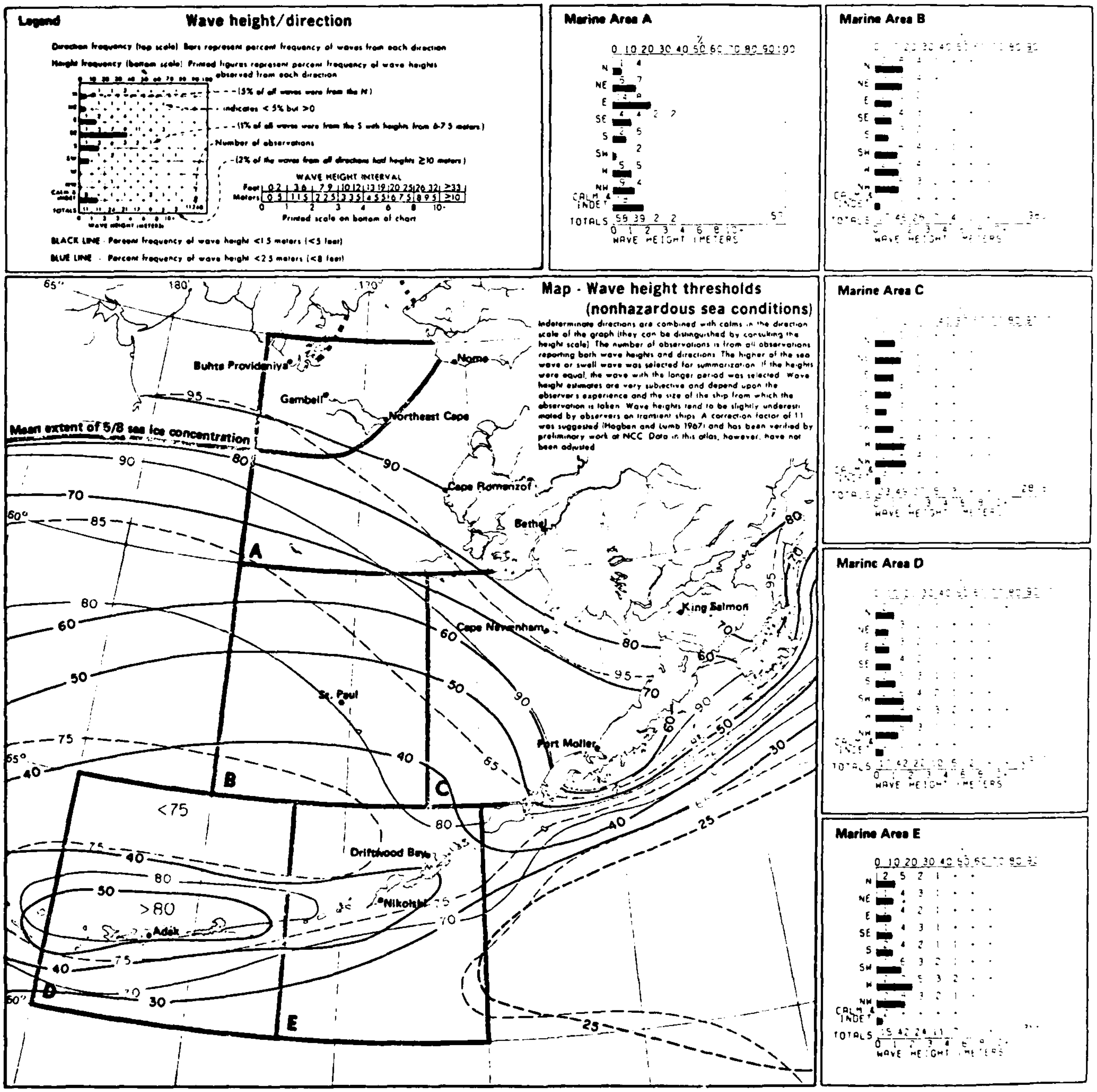


Figure 131. Wave height thresholds (nonhazardous), May (from Bering Sea ref. 2).

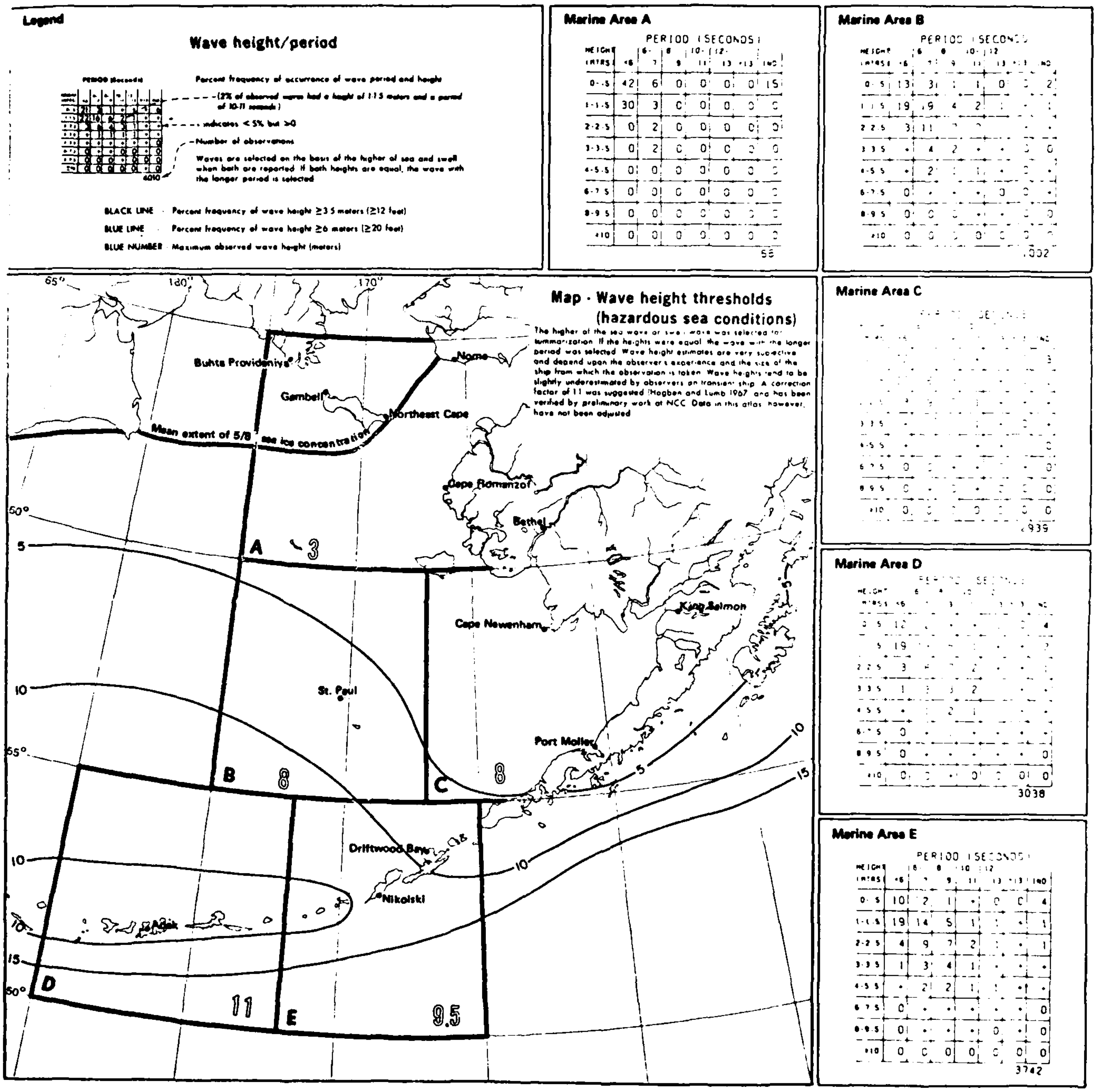


Figure 132. Wave height thresholds (hazardous), May (from Bering Sea ref. 2).

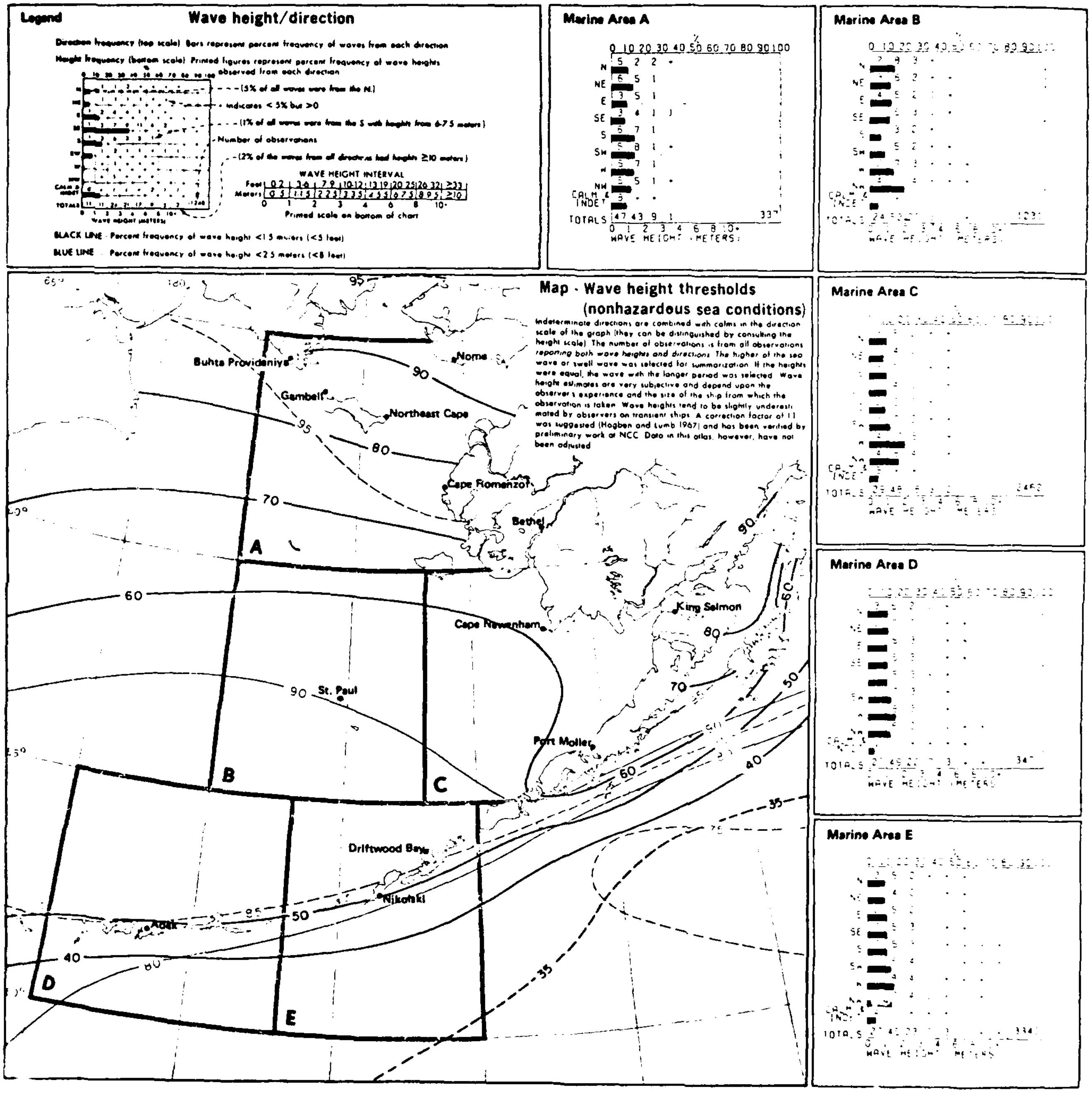


Figure 133. Wave height thresholds (nonhazardous), June (from Bering Sea ref. 2).

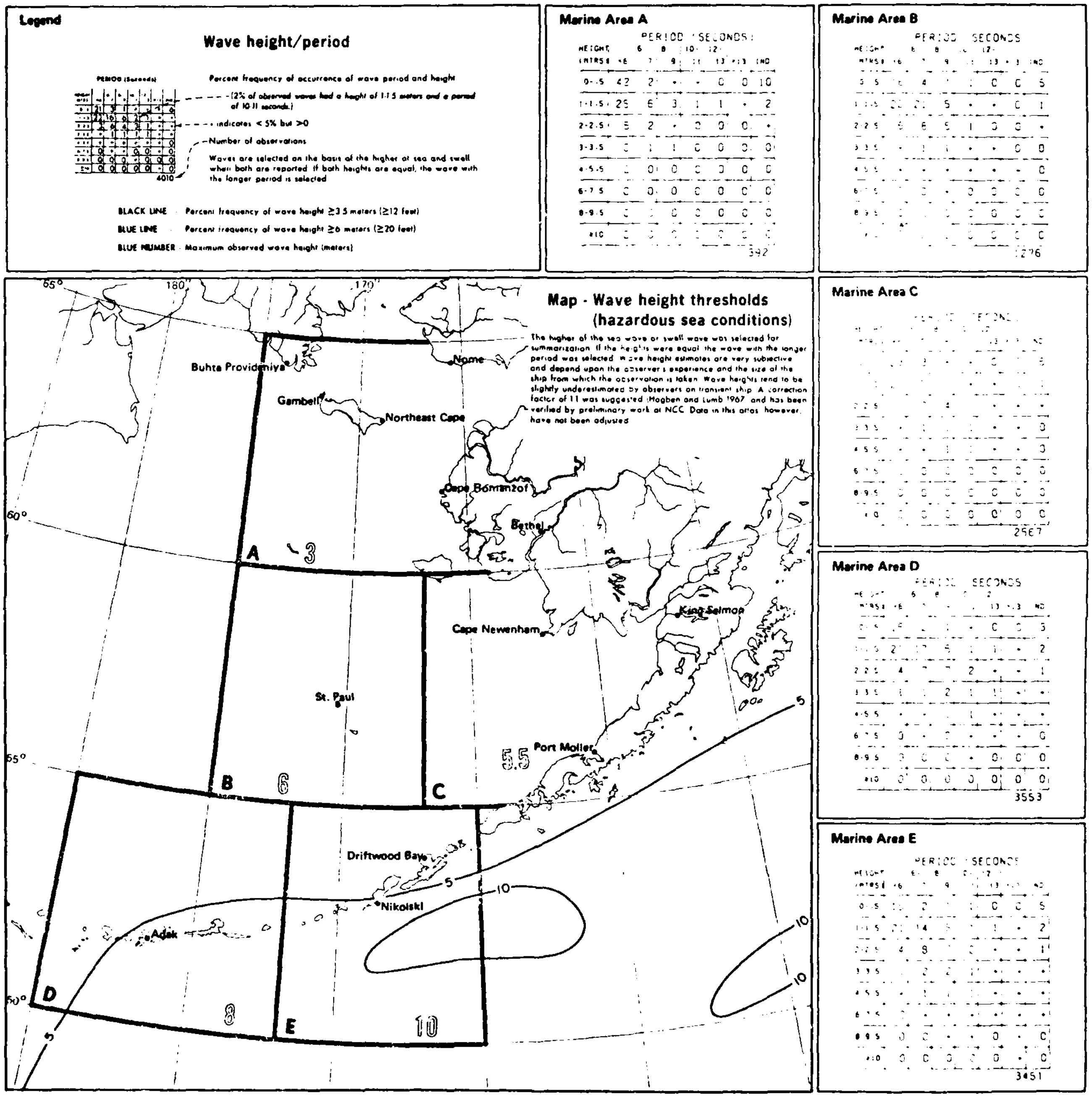


Figure 134. Wave height thresholds (hazardous), June (from Bering Sea ref. 2).

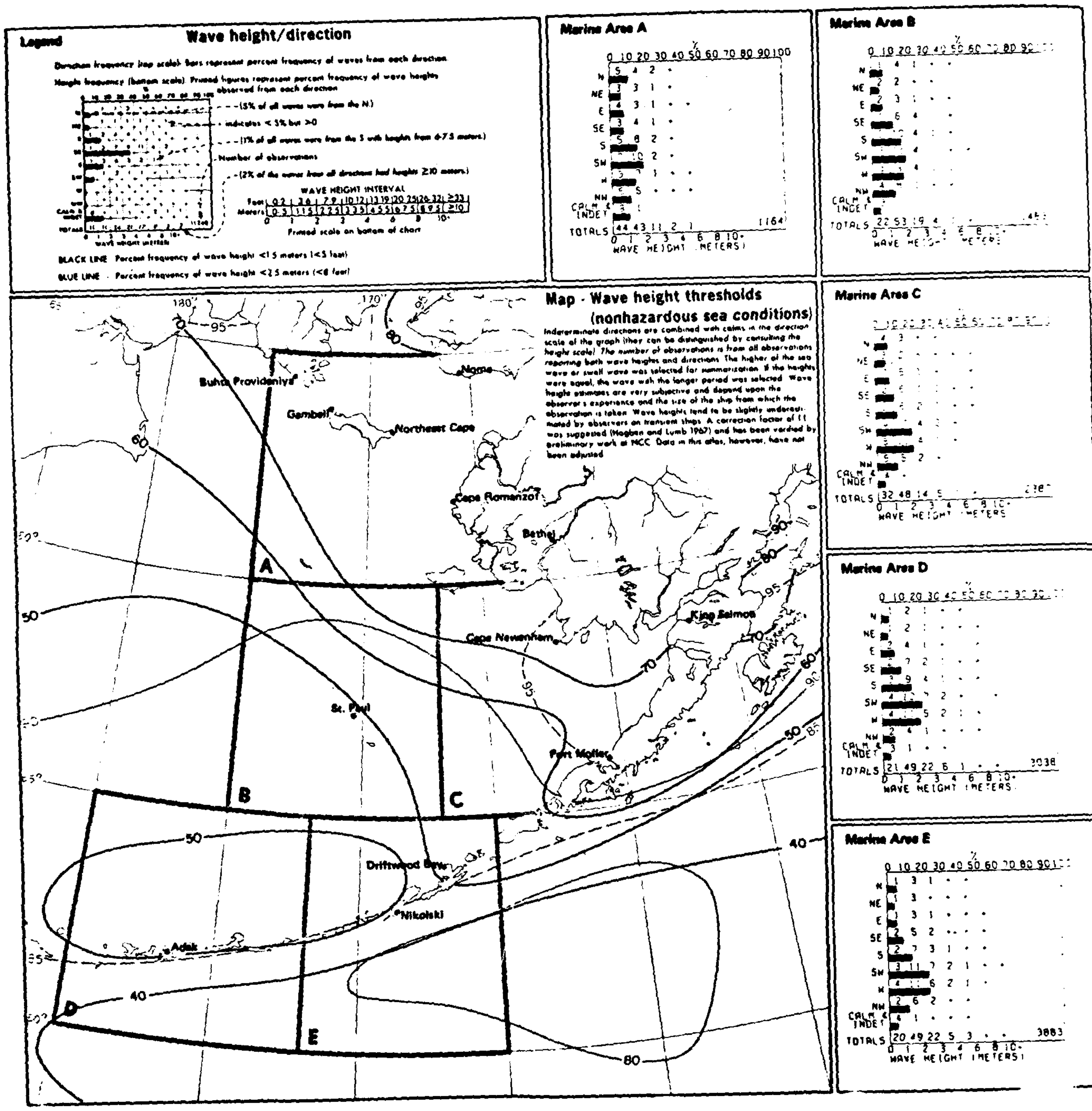
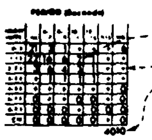


Figure 135. Wave height thresholds (nonhazardous), July (from Bering Sea ref. 2).

Legend

Wave height/period



Percent frequency of occurrence of wave period and height.

(2% of observed waves had a height of 1-1.5 meters and a period of 10-11 seconds.)

• indicates < 5% but >0

Number of observations

Waves are selected on the basis of the higher of sea and swell when both are reported. If both heights are equal, the wave with the longer period is selected.

BLACK LINE - Percent frequency of wave height ≥3.5 meters (≥12 feet)

BLUE LINE - Percent frequency of wave height ≥6 meters (≥20 feet)

BLUE NUMBER Maximum observed wave height (meters)

Marine Area A

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	32	3	1	2	0	0	10
1-1.5	23	9	3	•	1	•	3
2-2.5	4	5	1	•	0	•	•
3-3.5	•	•	1	•	0	0	•
4-5.5	0	•	•	0	•	0	0
6-7.5	0	0	0	0	0	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

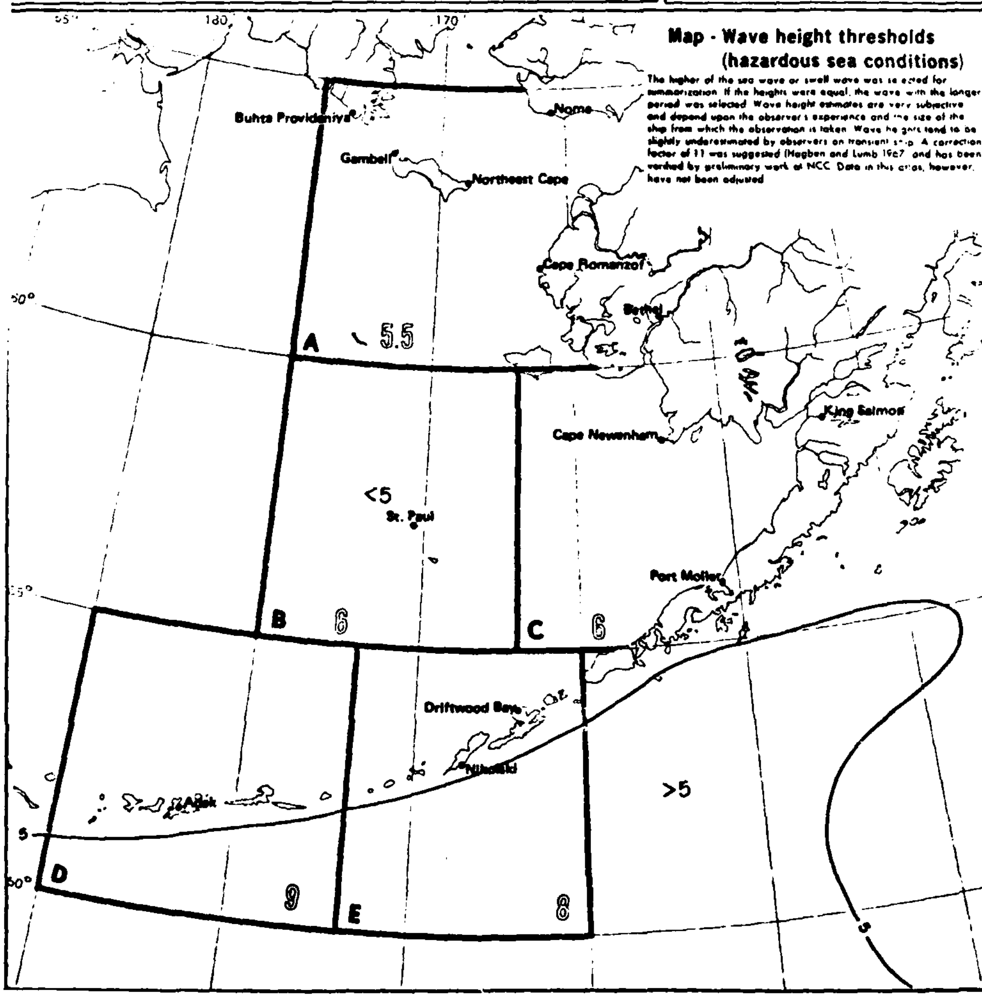
1273

Marine Area B

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	15	3	1	•	0	0	5
1-1.5	20	22	7	1	0	0	2
2-2.5	3	9	5	1	0	0	•
3-3.5	•	1	2	•	•	•	1
4-5.5	•	•	1	•	•	•	0
6-7.5	0	0	0	0	0	•	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

1519



Marine Area C

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	27	2	1	•	0	0	4
1-1.5	25	16	3	•	•	•	1
2-2.5	3	5	4	1	•	0	•
3-3.5	•	1	2	1	1	•	•
4-5.5	•	0	•	•	•	0	0
6-7.5	0	0	0	•	•	0	0
8-9.5	0	0	0	0	0	0	0
≥10	0	0	0	0	0	0	0

2501

Marine Area D

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	15	2	2	•	0	0	4
1-1.5	22	16	6	1	•	•	2
2-2.5	4	8	6	2	•	•	1
3-3.5	1	2	2	1	•	•	•
4-5.5	0	•	•	•	•	•	•
6-7.5	0	•	•	•	•	•	0
8-9.5	0	0	0	0	0	•	•
≥10	0	0	0	0	0	0	0

3157

Marine Area E

PERIOD (SECONDS)

HEIGHT (MTRS)	<6	6-7	8-9	10-11	12-13	>13	IND
0-.5	14	2	1	•	0	0	5
1-1.5	21	18	5	1	•	•	2
2-2.5	4	9	6	2	•	•	•
3-3.5	1	4	2	1	•	•	•
4-5.5	•	1	1	•	•	•	•
6-7.5	0	•	•	•	•	0	•
8-9.5	0	0	0	0	•	0	0
≥10	0	0	0	0	0	0	0

4031

Figure 136. Wave height thresholds (hazardous), July (from Bering Sea ref. 2).

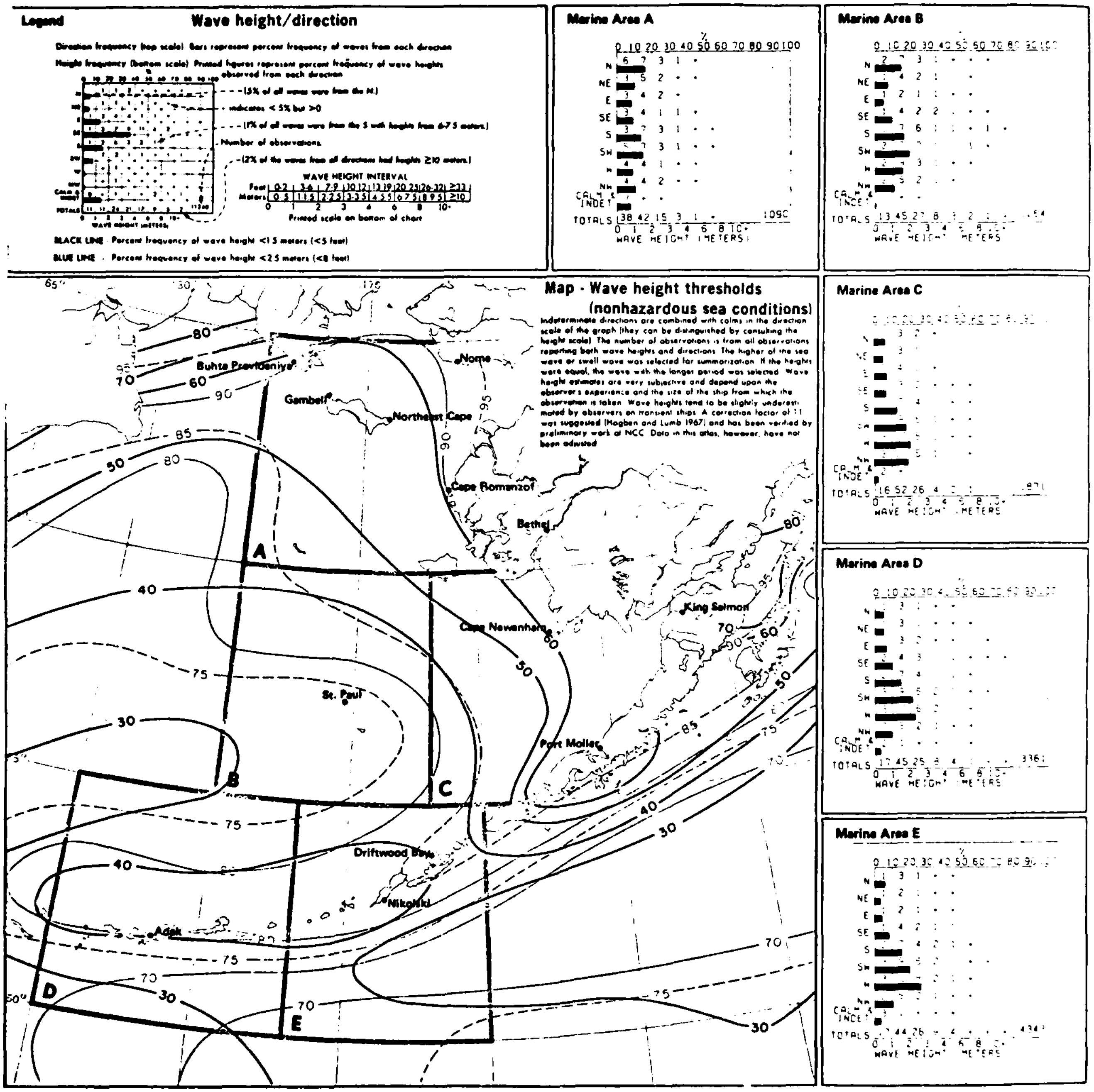


Figure 137. Wave height thresholds (nonhazardous), August (from Bering Sea ref. 2).

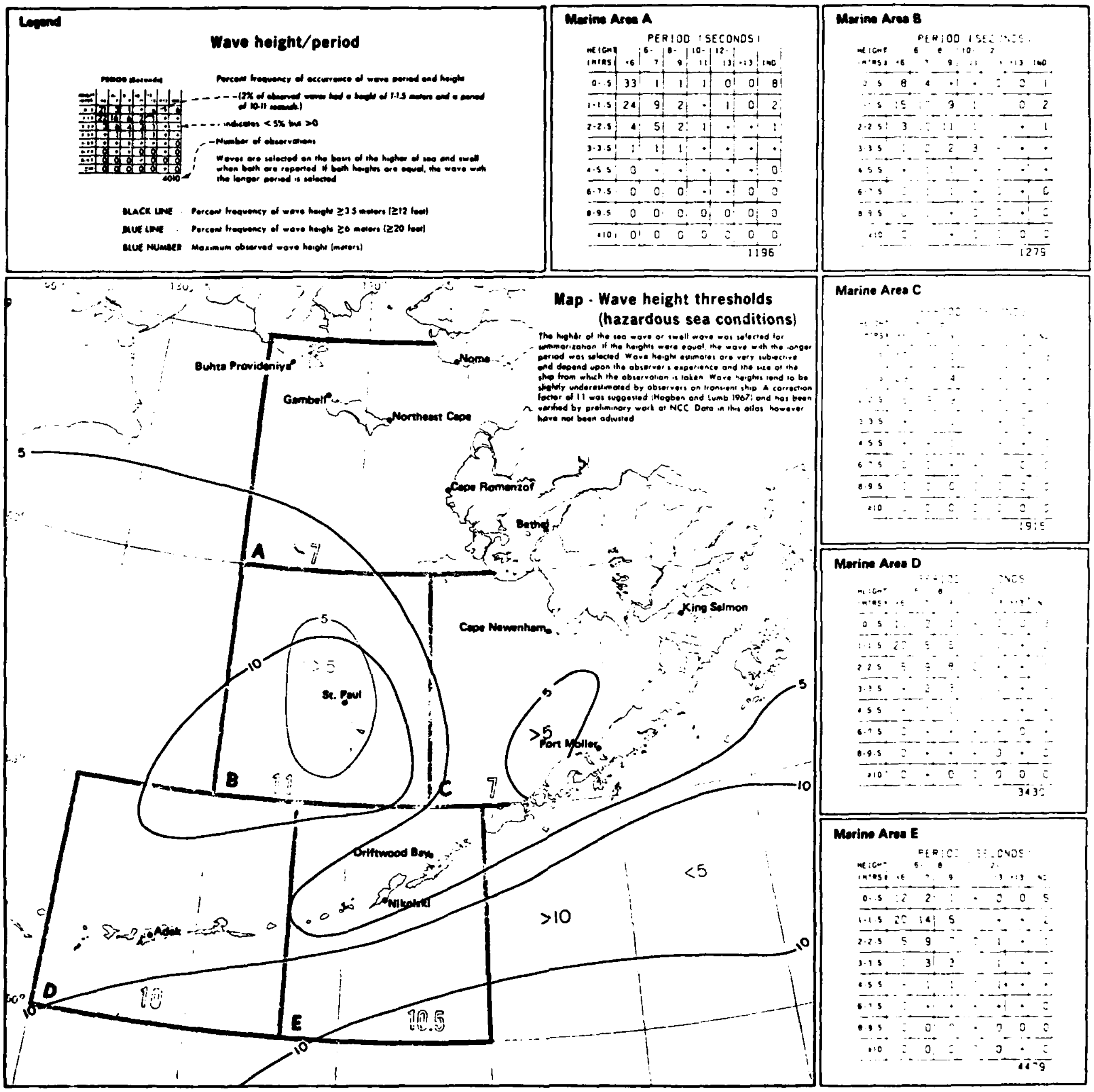


Figure 138. Wave height thresholds (hazardous), August (from Bering Sea ref. 2).

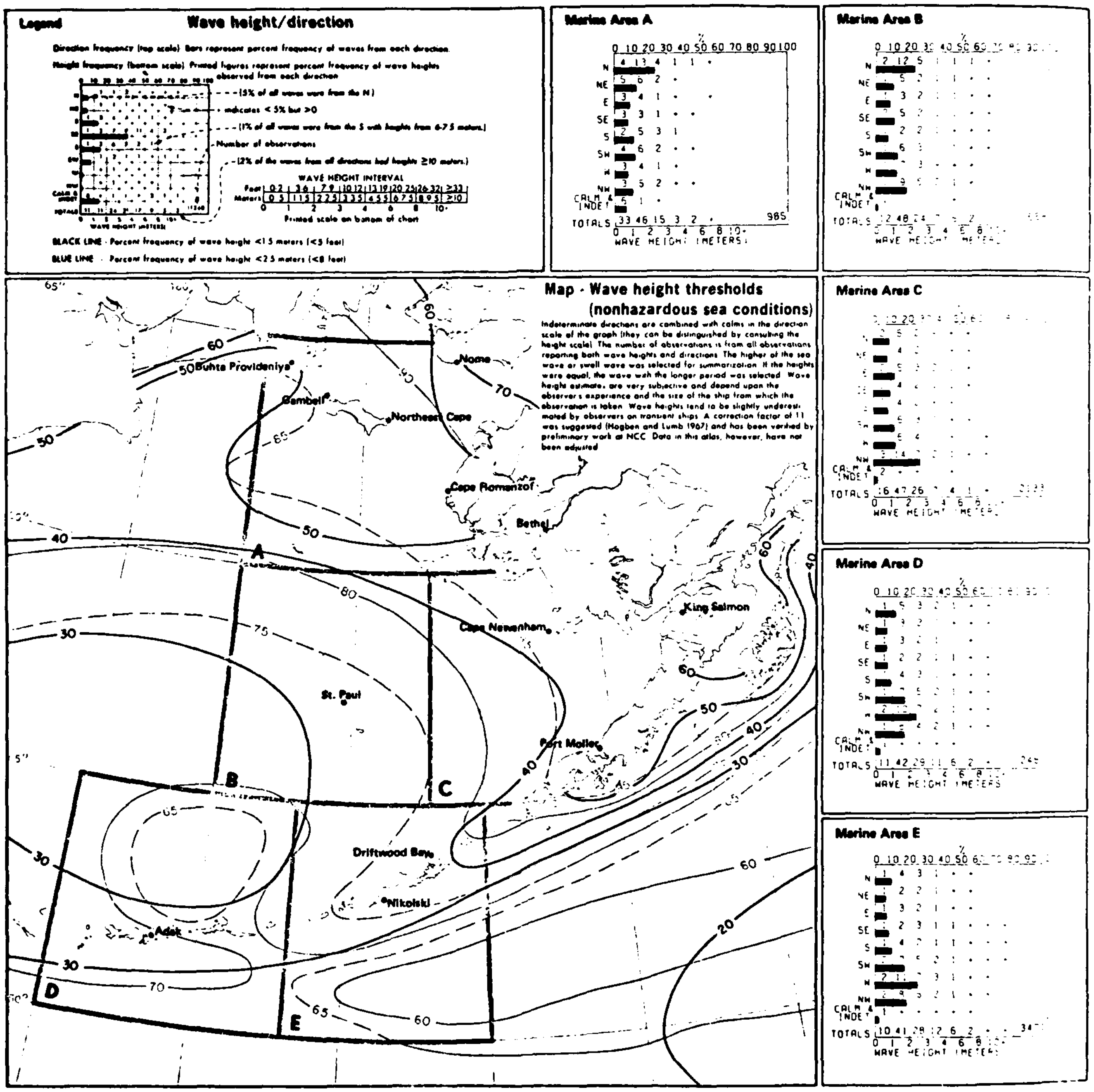


Figure 139. Wave height thresholds (nonhazardous), September (from Bering Sea ref. 2).

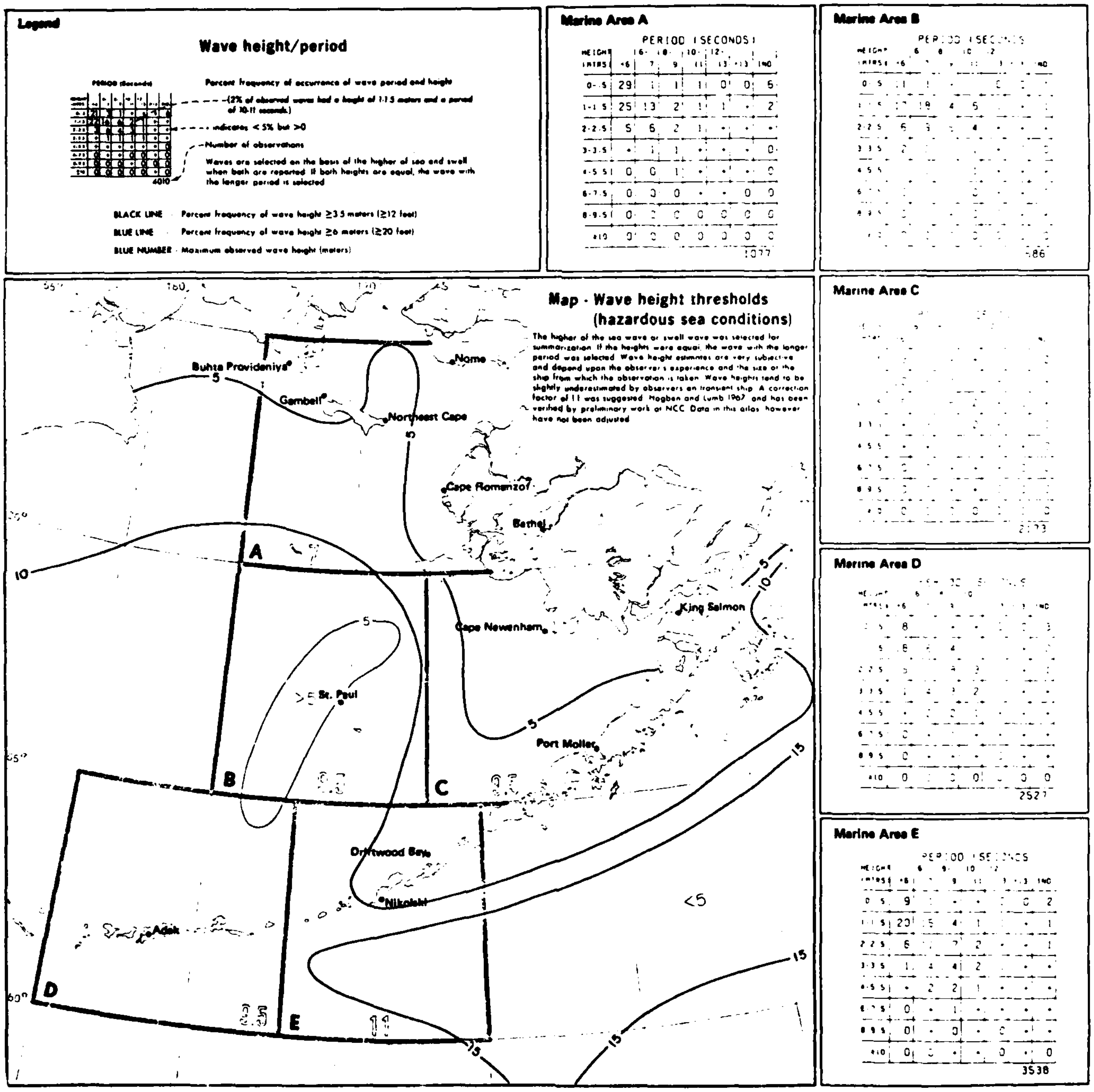


Figure 140. Wave height thresholds (hazardous), September (from Bering Sea ref. 2).

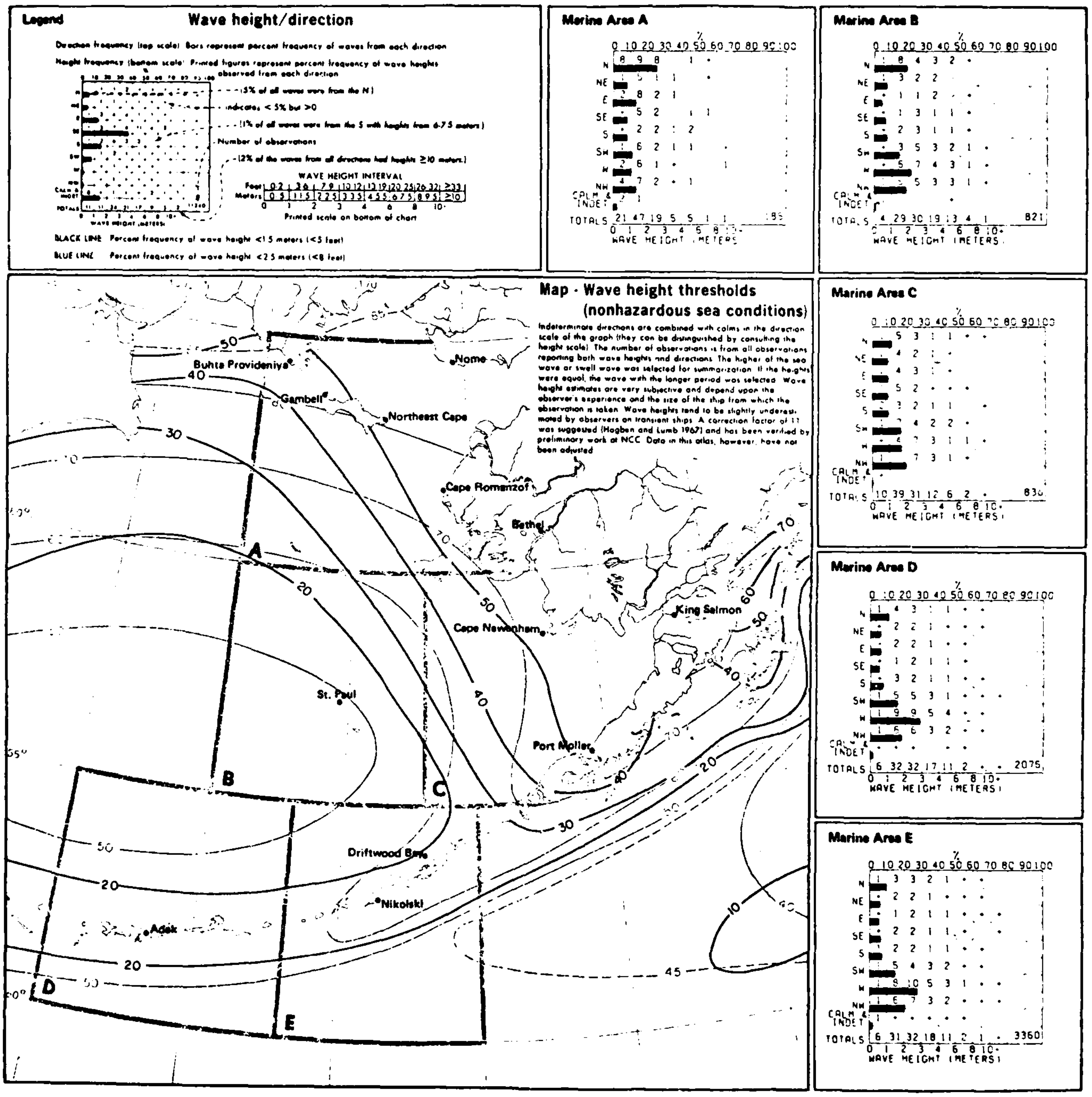


Figure 141. Wave height thresholds (nonhazardous), October (from Bering Sea ref. 2).

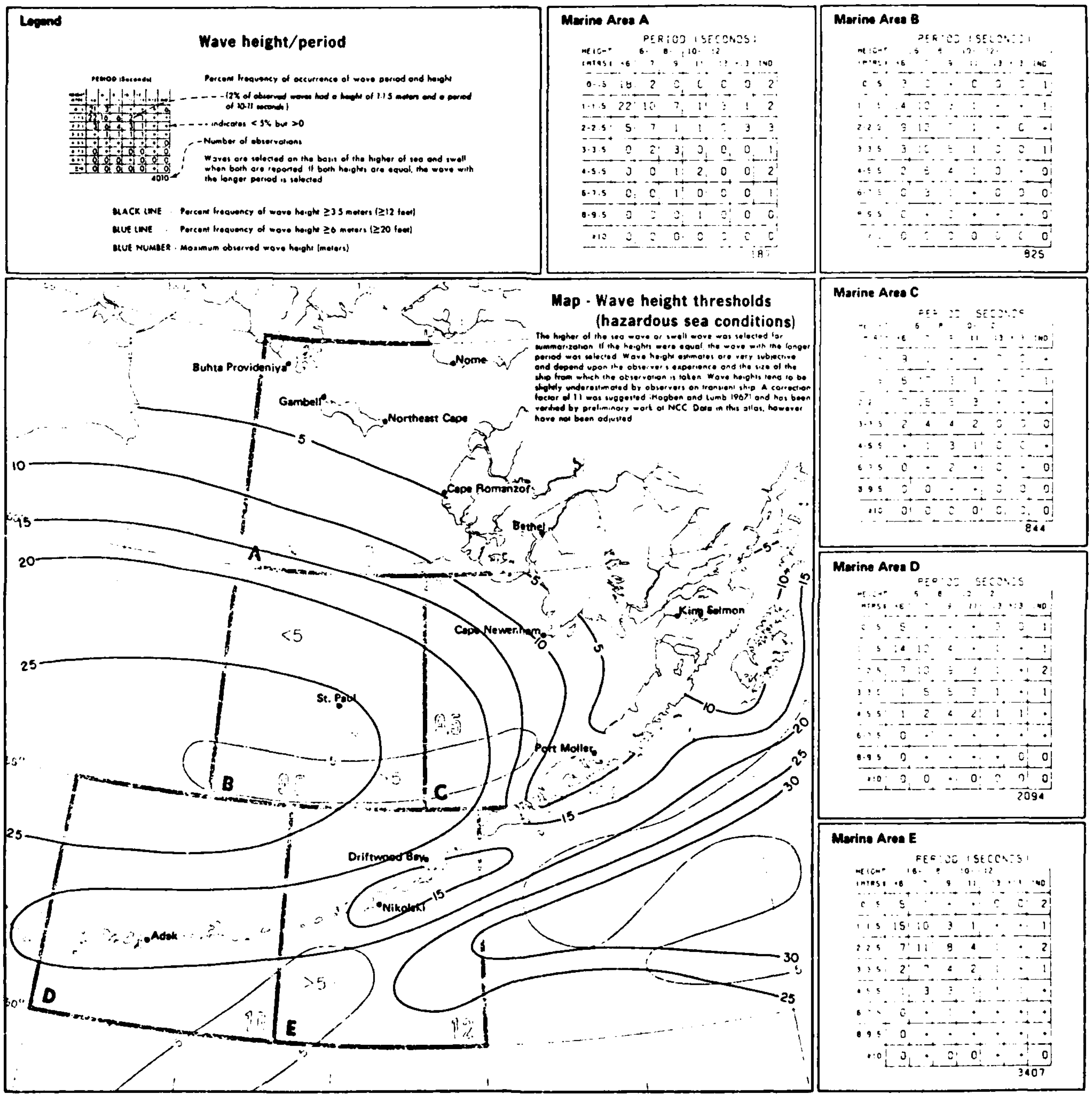


Figure 142. Wave height thresholds (hazardous), October (from Bering Sea ref. 2).

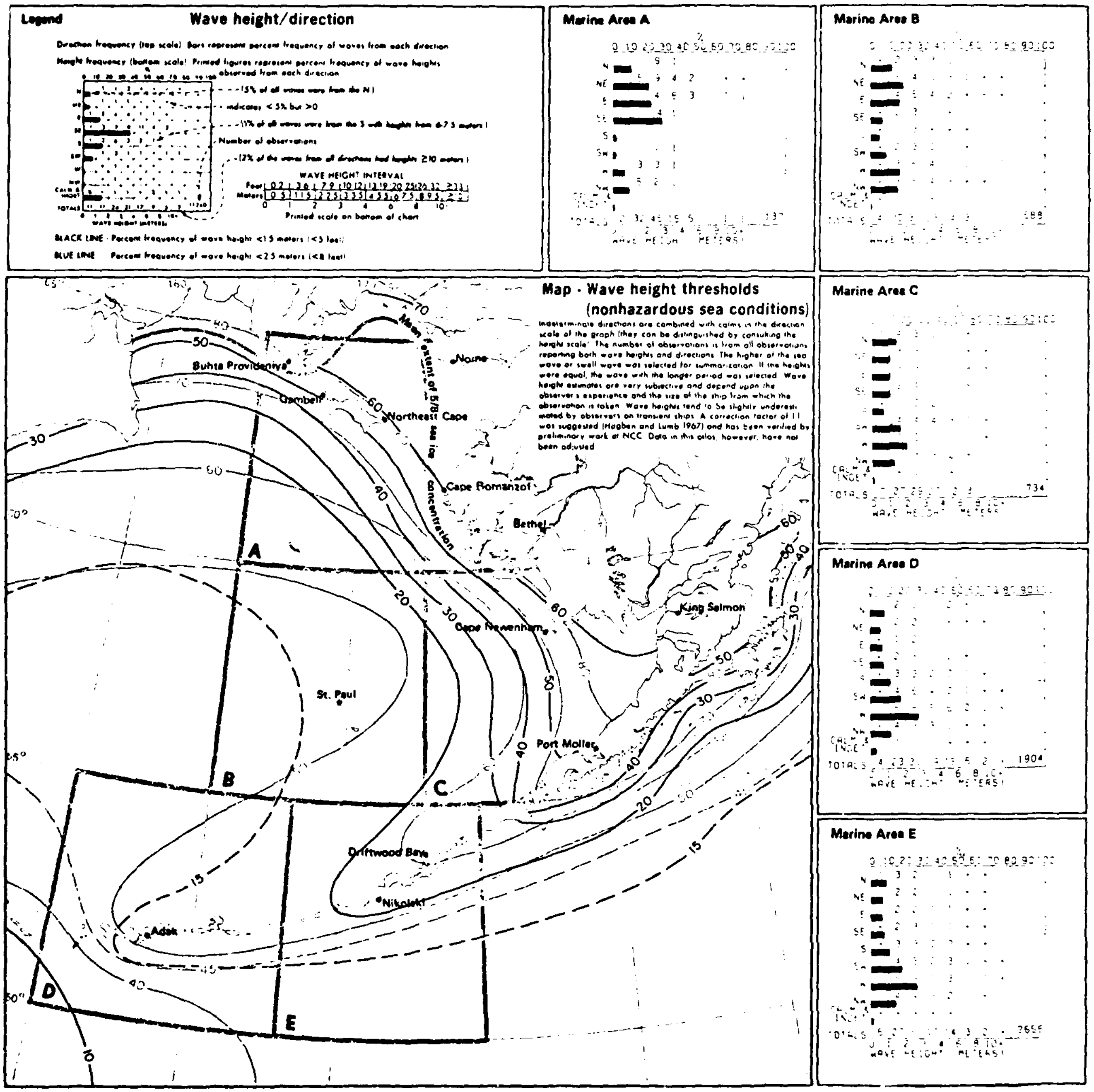


Figure 143. Wave height thresholds (nonhazardous), November (from Bering Sea ref. 2).

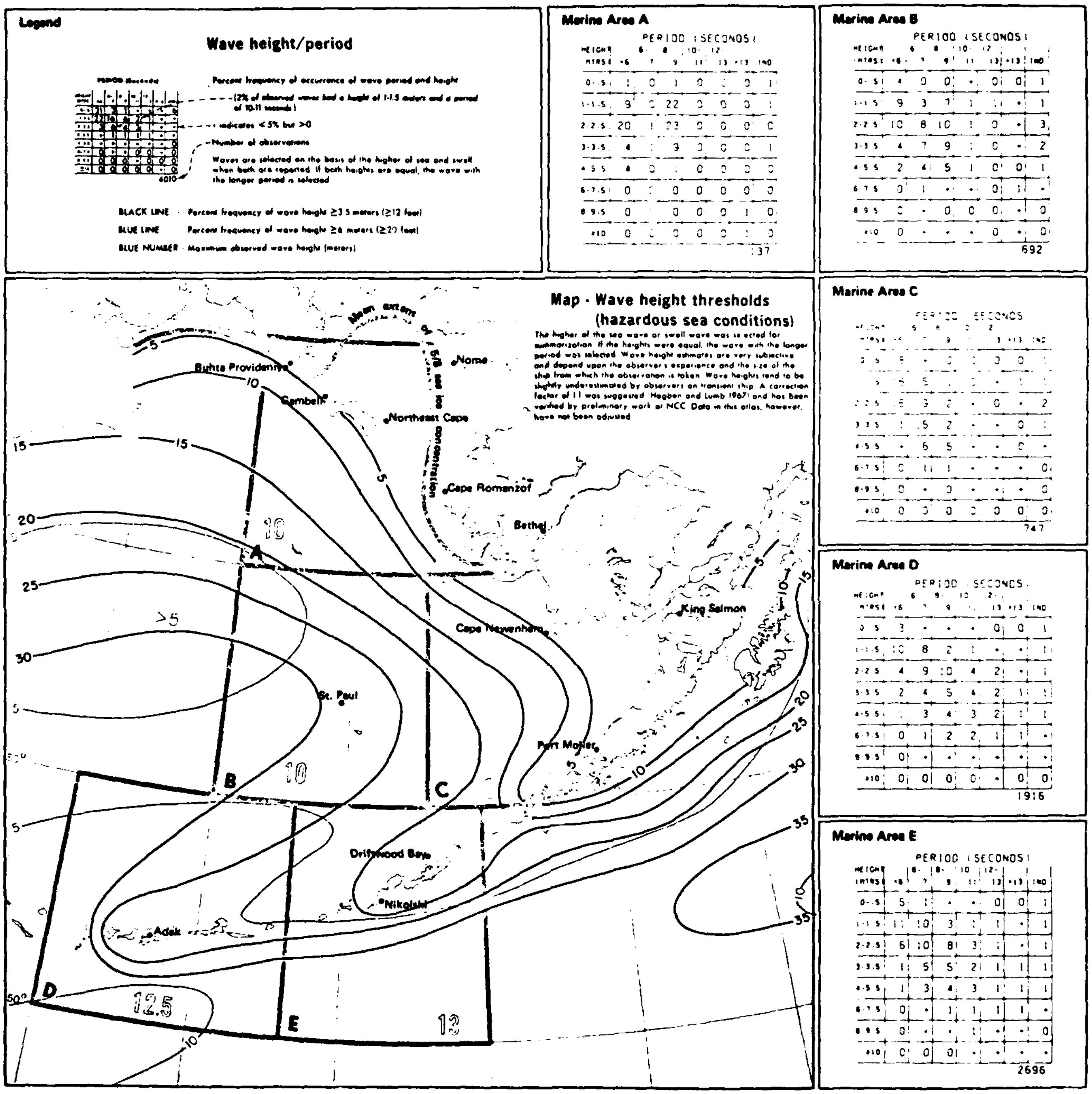


Figure 144. Wave height thresholds (hazardous), November (from Bering Sea ref. 2).

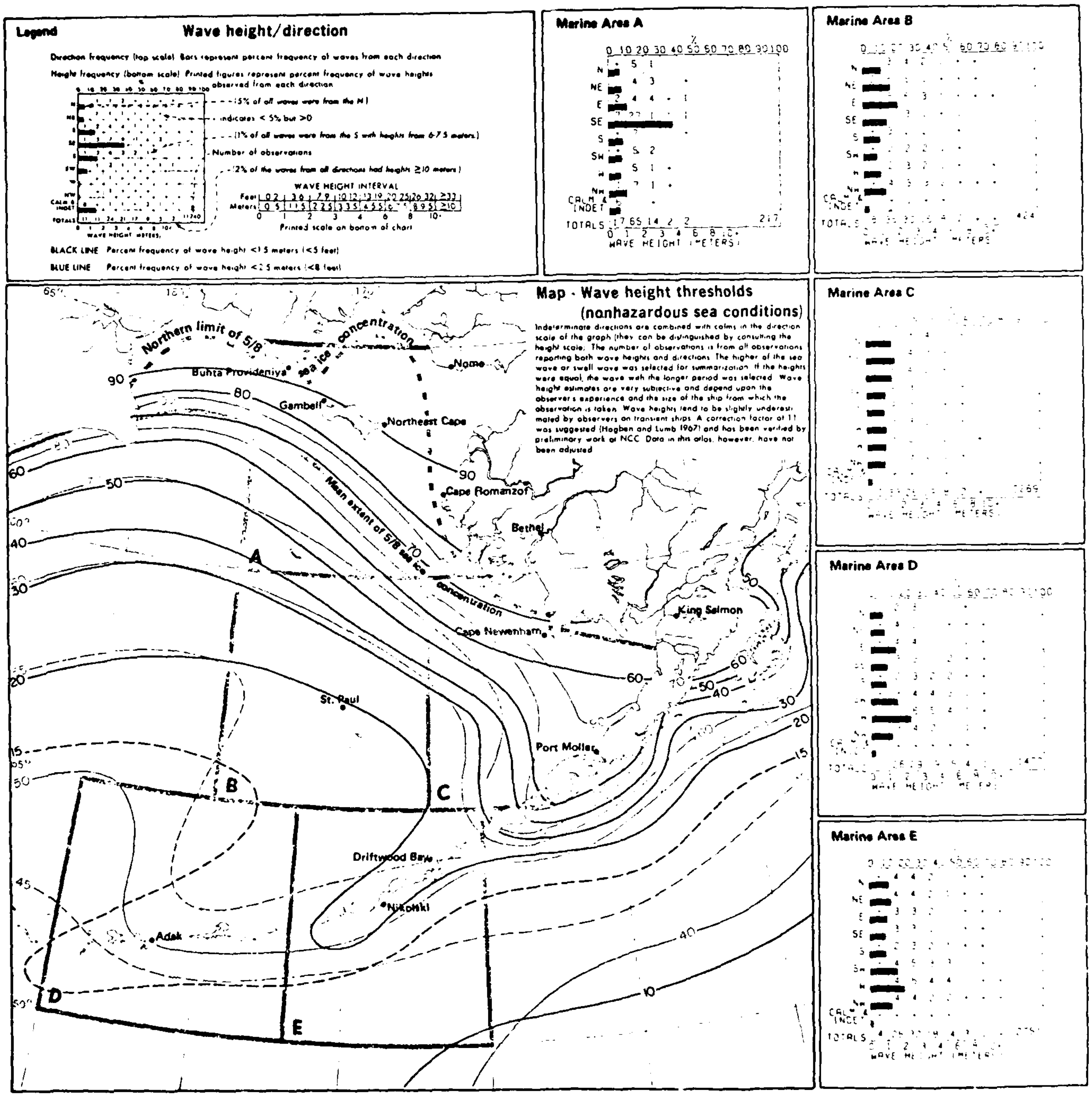


Figure 145. Wave height thresholds (nonhazardous), December (from Bering Sea ref. 2).

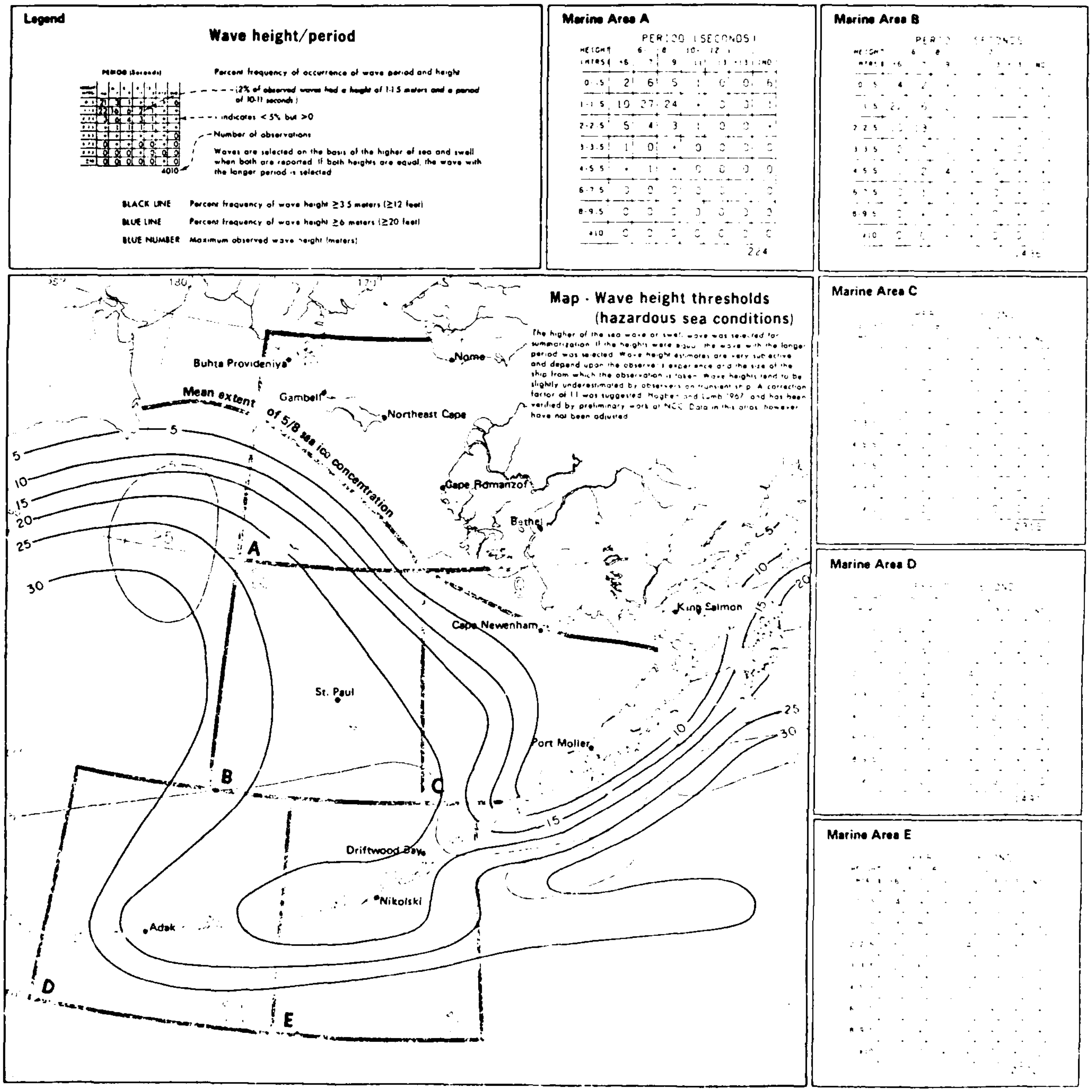


Figure 146. Wave height thresholds (hazardous), December (from Bering Sea ref. 2).

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COASTAL ENVIRONMENT, BATHYMETRY AND PHYSICAL OCEANOGRAPHY ALONG--ETC(U)
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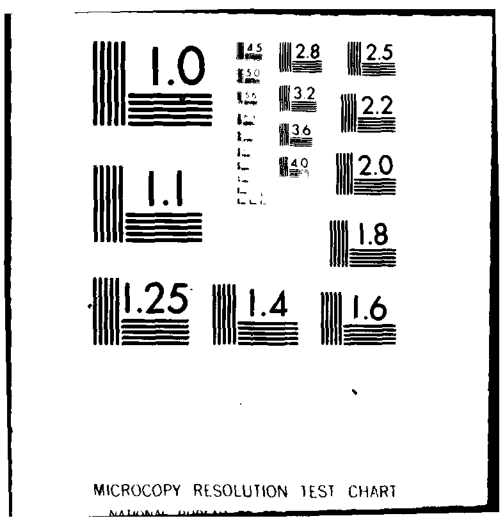

1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
MICROCOPY RESOLUTION TEST CHART

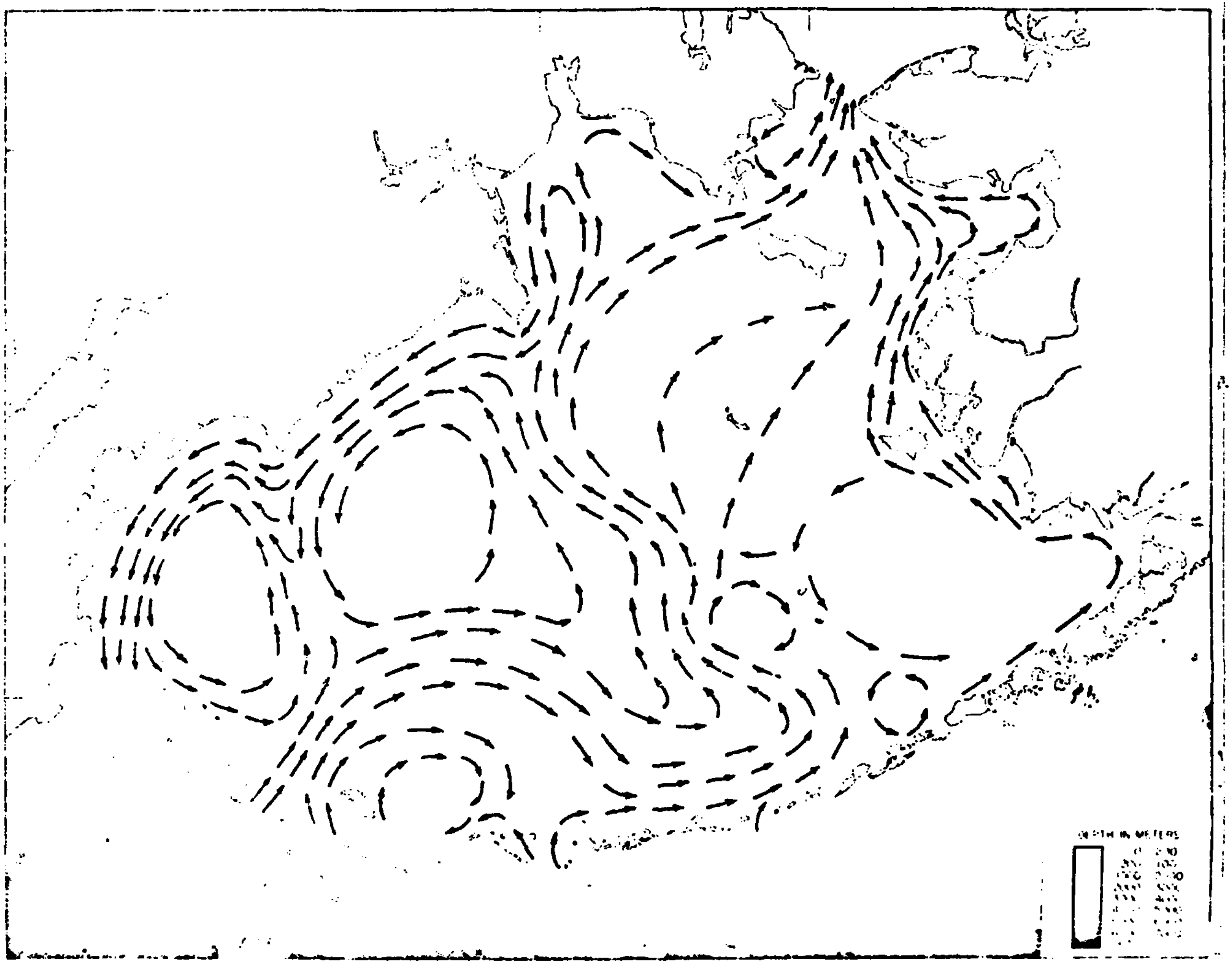


Figure 147. Surface circulation during summer (from Bering Sea ref. 17).

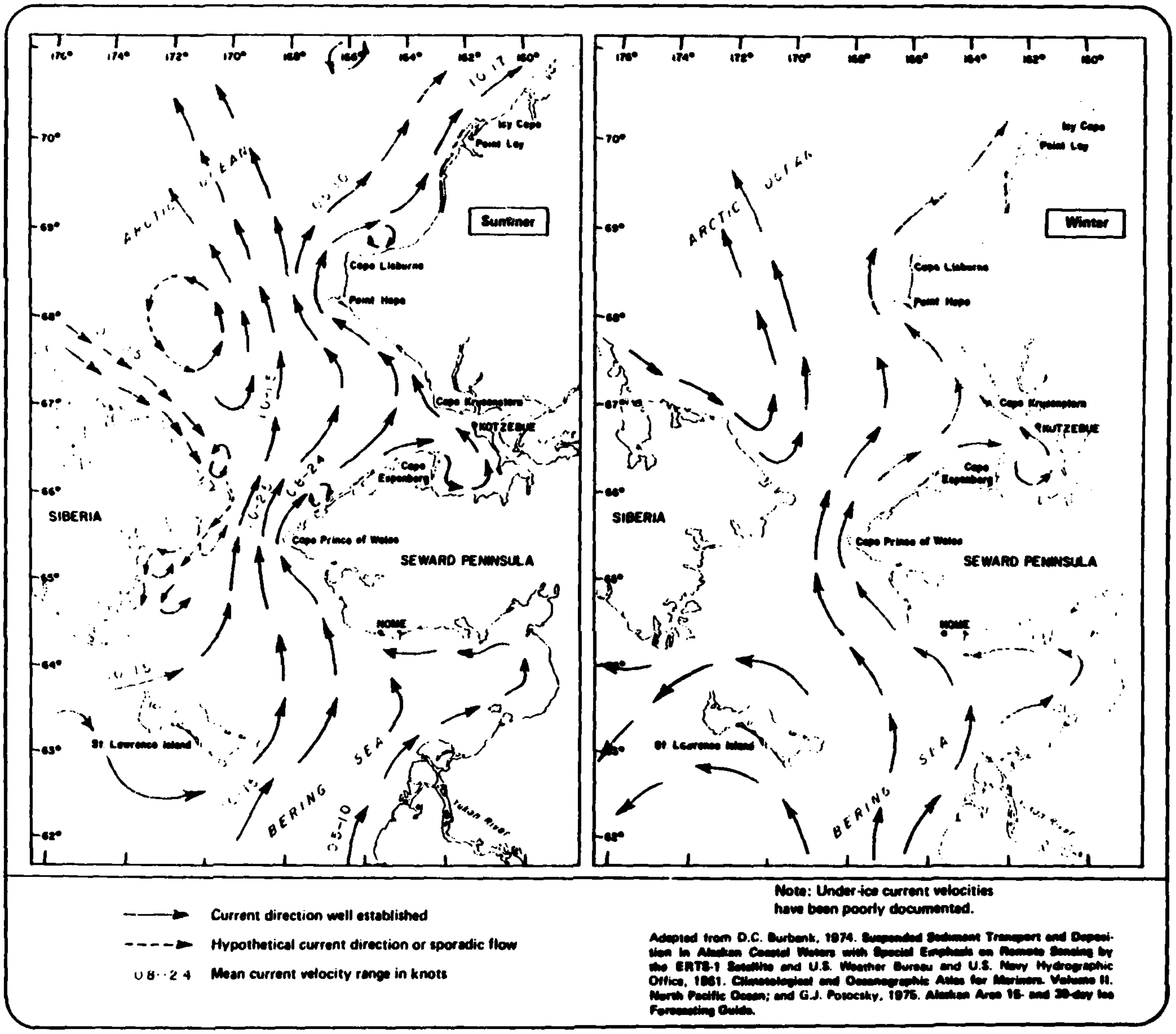


Figure 148. Surface water circulation pattern in summer and winter (from Bering Sea ref. 1.)

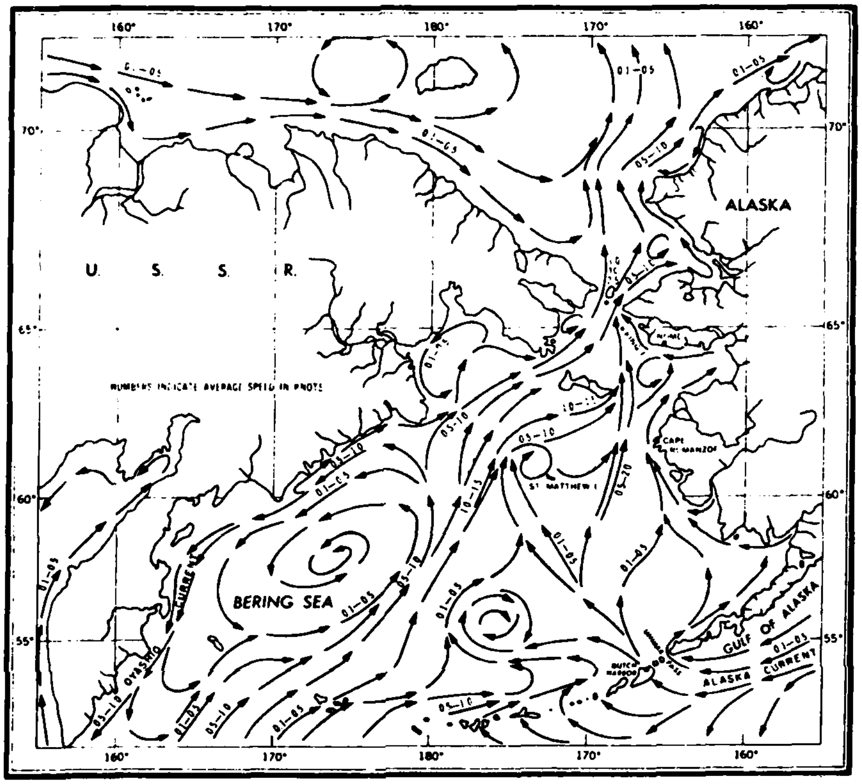


Figure 149. Bering Sea circulation according to U.S. Navy Hydrographic Office (1958) (from Bering Sea ref. 11).

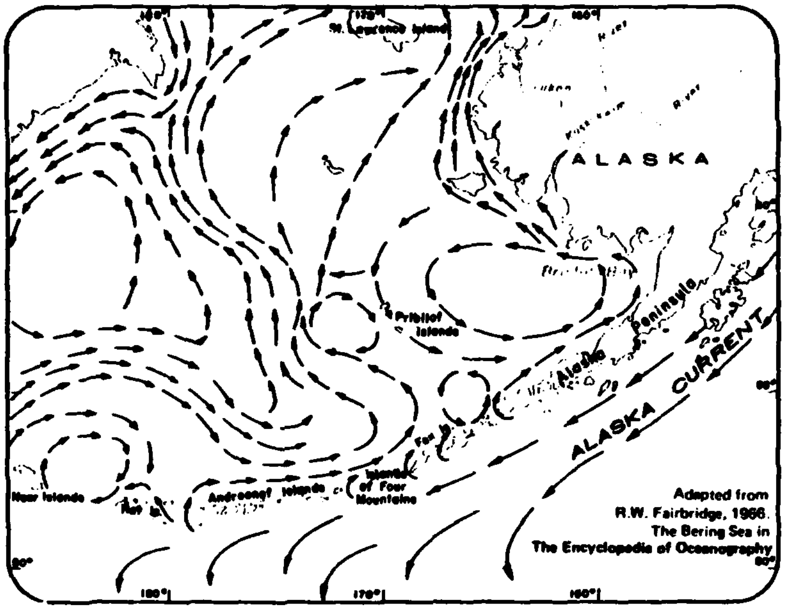


Figure 150. Surface circulation in the Bering Sea (from Bering Sea ref. 1).

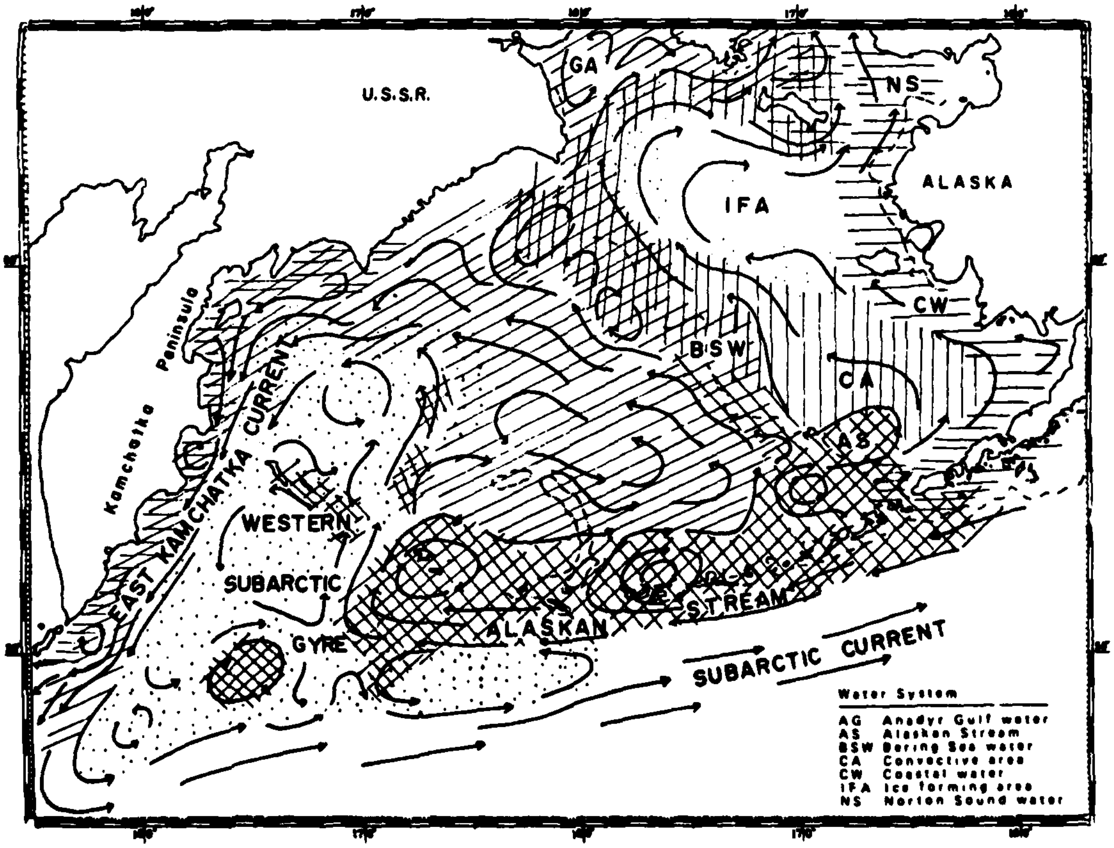


Figure 151. Schematic diagram of circulation and extent of water masses in the Bering Sea and northwestern Pacific Ocean (from Bering Sea ref. 10).

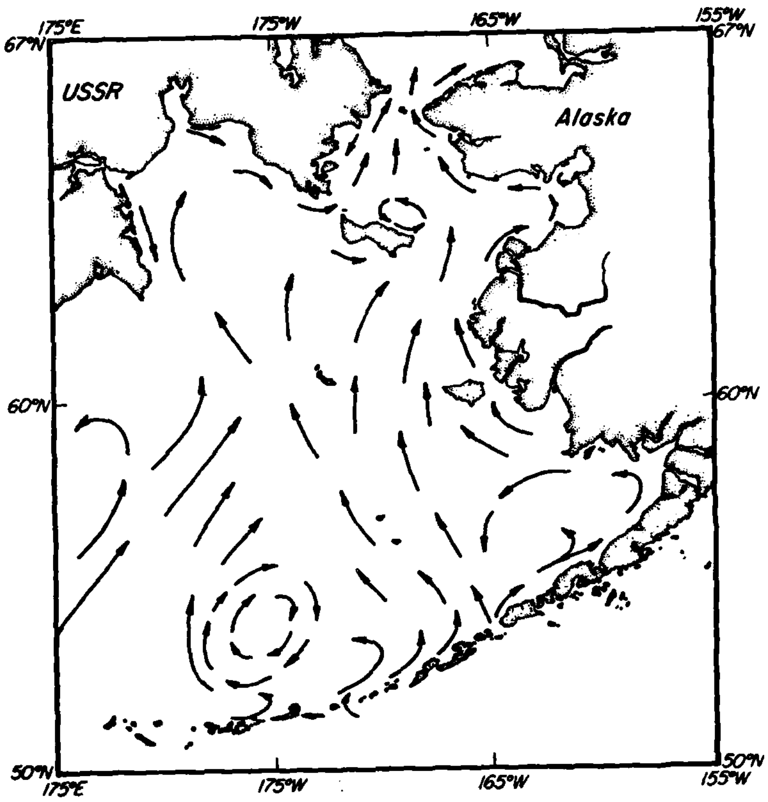


Figure 152. Major currents in eastern Bering Sea (from Bering Sea ref. 11).

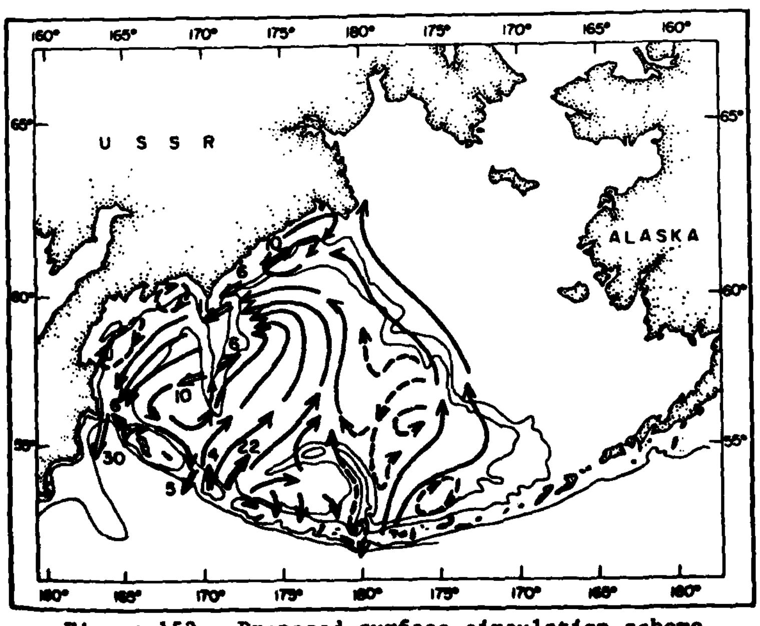


Figure 153. Proposed surface circulation scheme. Double arrow is measured flow vector, with speed in cm/sec (from Bering Sea ref. 11).

Qualitative key:
——→ certain
– – – –→ less certain
⇒ direct measurements (cm/sec)

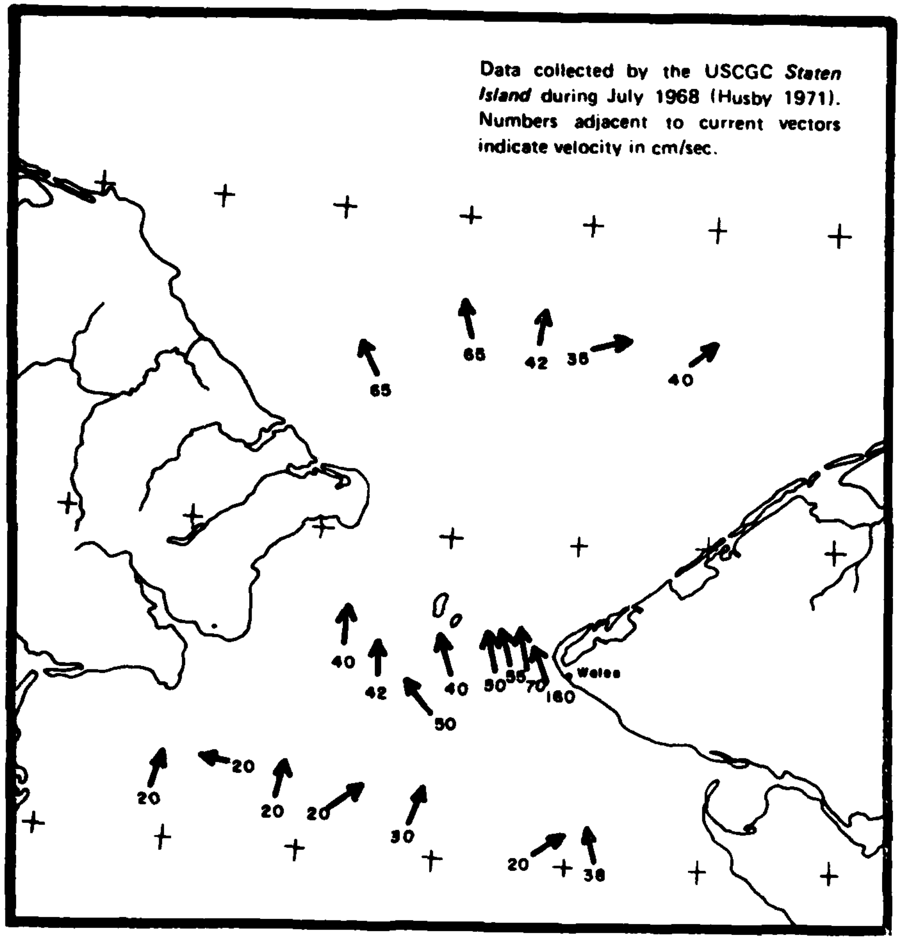


Figure 154. Current velocity at a five-meter depth through Bering Strait (from Chukchi Sea ref. 12).

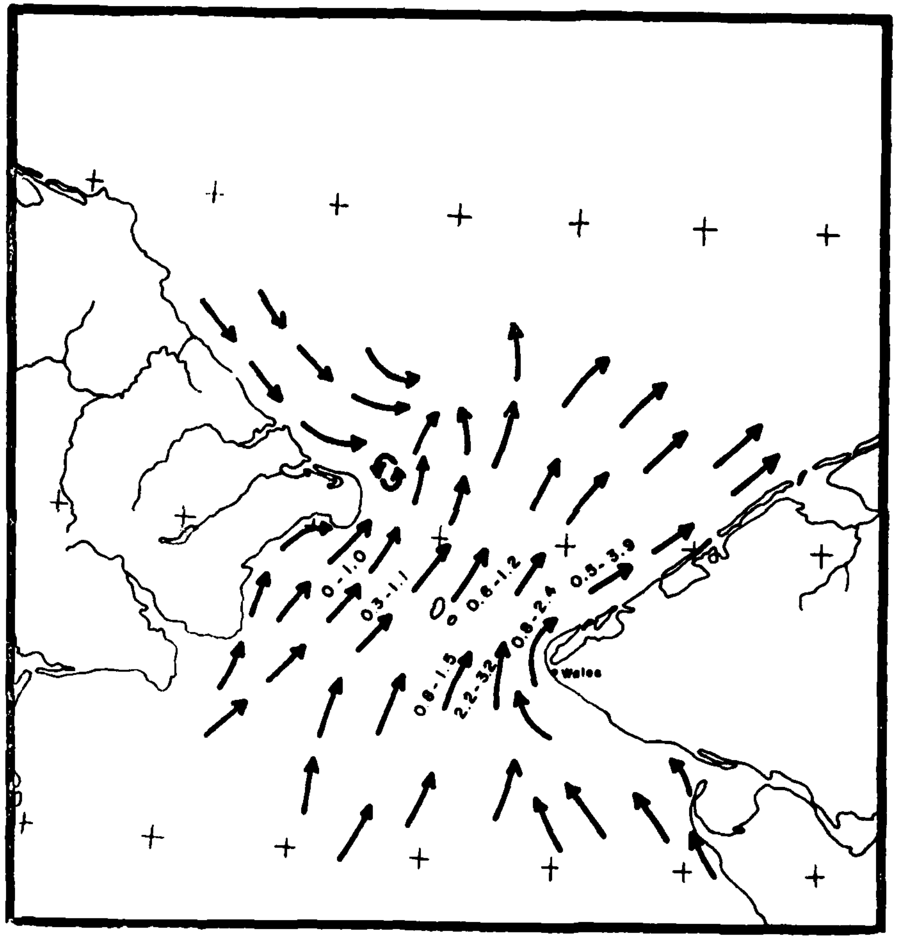
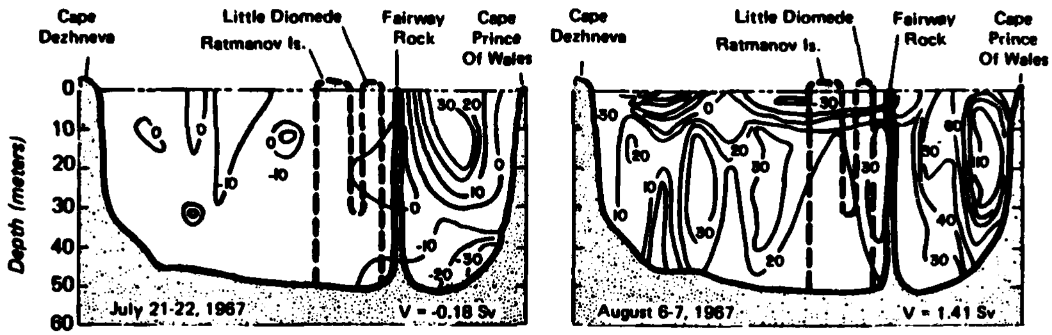


Figure 155. Average surface currents in the Bering Strait in knots (U.S. Navy Hydrographic Office 1968) (from Chukchi Sea ref. 12).



—10— Isotachs in cm/second

+ Indicates northerly flow

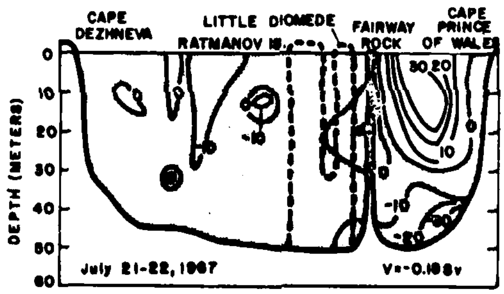
- Indicates southerly flow

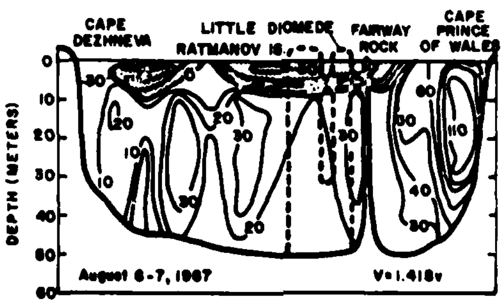
☐ South-flowing masses of water

Note: On the left the net movement of water through Bering Strait was to the south at 0.18 Sverdrup (Sv). A more typical northward flow is illustrated on the right. 1.0 Sv = 1.0 x 10^6 m^3/sec

Source: Coachman, L.K. and K. Aagaard. 1974. Physical oceanography of Arctic and subarctic seas in Marine Geology and Oceanography of the Arctic Seas.

Figure 156. Cross section of Bering Strait illustrating water flow in summer (from Bering Sea ref. 1).





Isotachs are in cm/sec with (+) indicating northerly flow and (-) indicating southerly flow. South-flowing masses of water are shown as stippled areas. (After Coachman and Aagaard 1974). Note that in the upper illustration, the net movement of water through the strait is to the south at 0.18 Sv. A more typical northward flow is illustrated in the lower diagram.

Figure 157. Cross sections of flow through Bering Strait in summer 1967 from Northwind cruise data (from Chukchi Sea ref. 12).

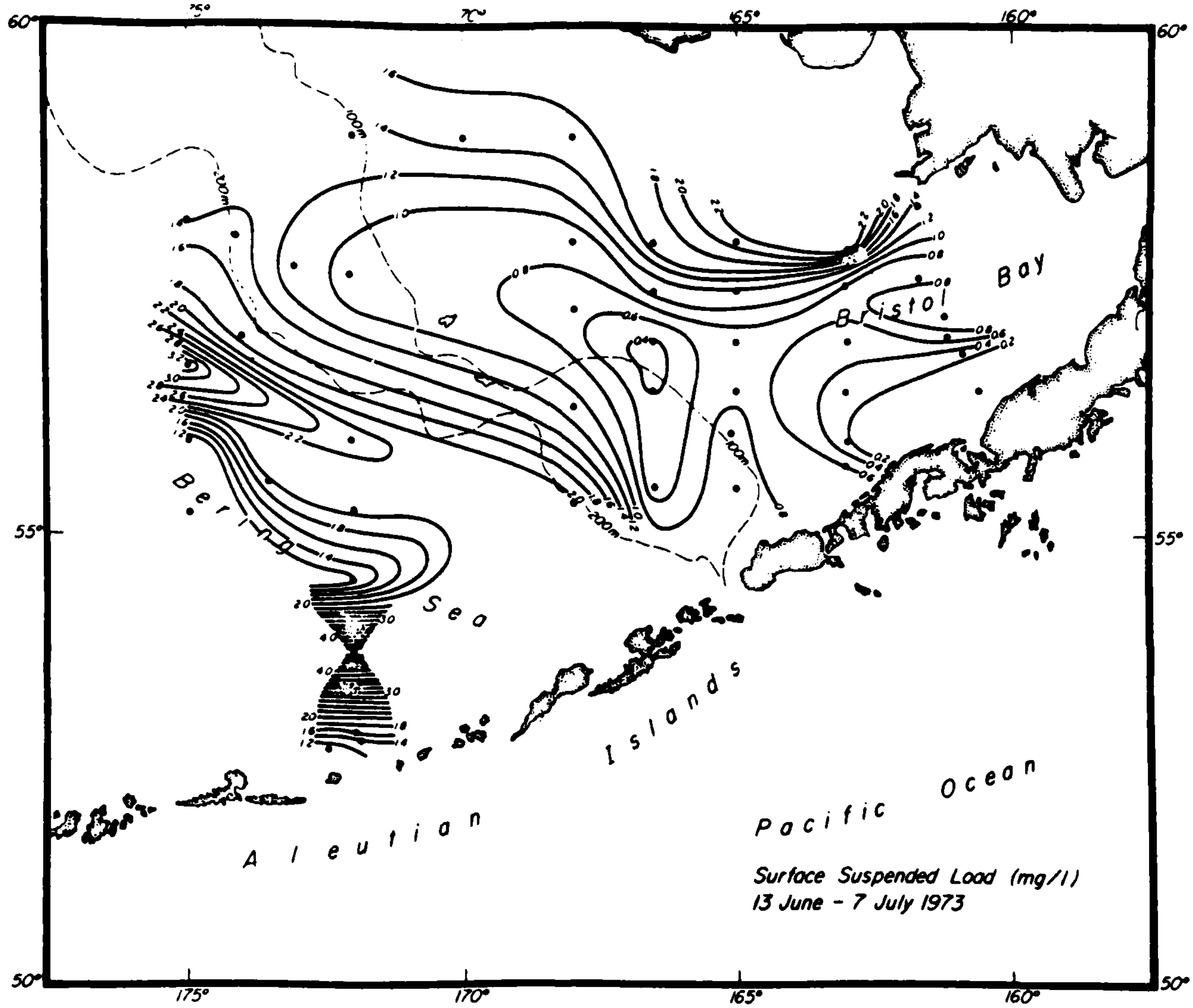


Figure 158. Surface suspended load distribution (mg/l) in the southeastern Bering Sea, 13 June-7 July 1973 (from Chukchi Sea ref. 15).

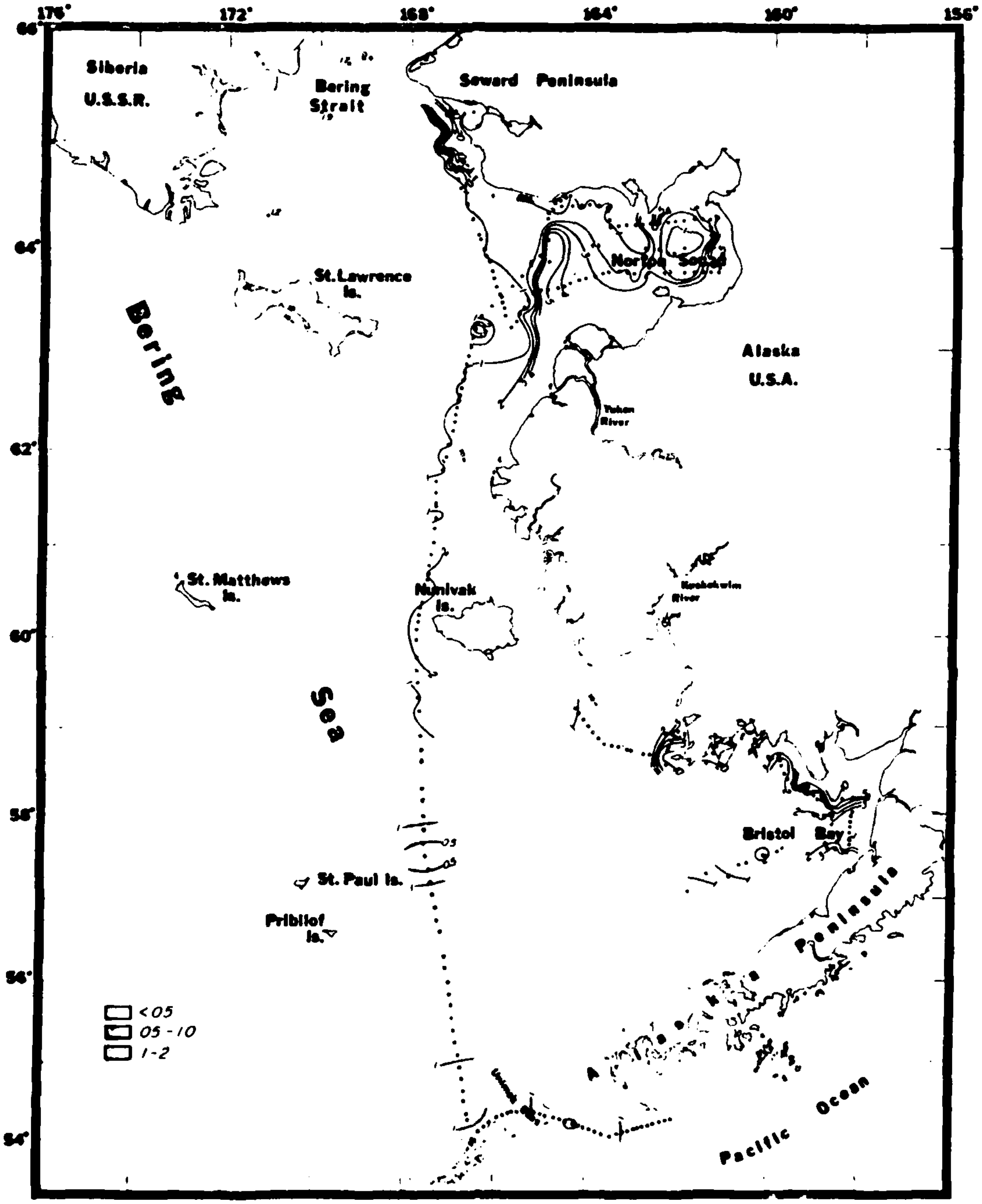


Figure 159. Surface suspended load distribution (mg/l) in the eastern Bering Sea; 11 July-11 August 1973 (from Chukchi Sea ref. 15).

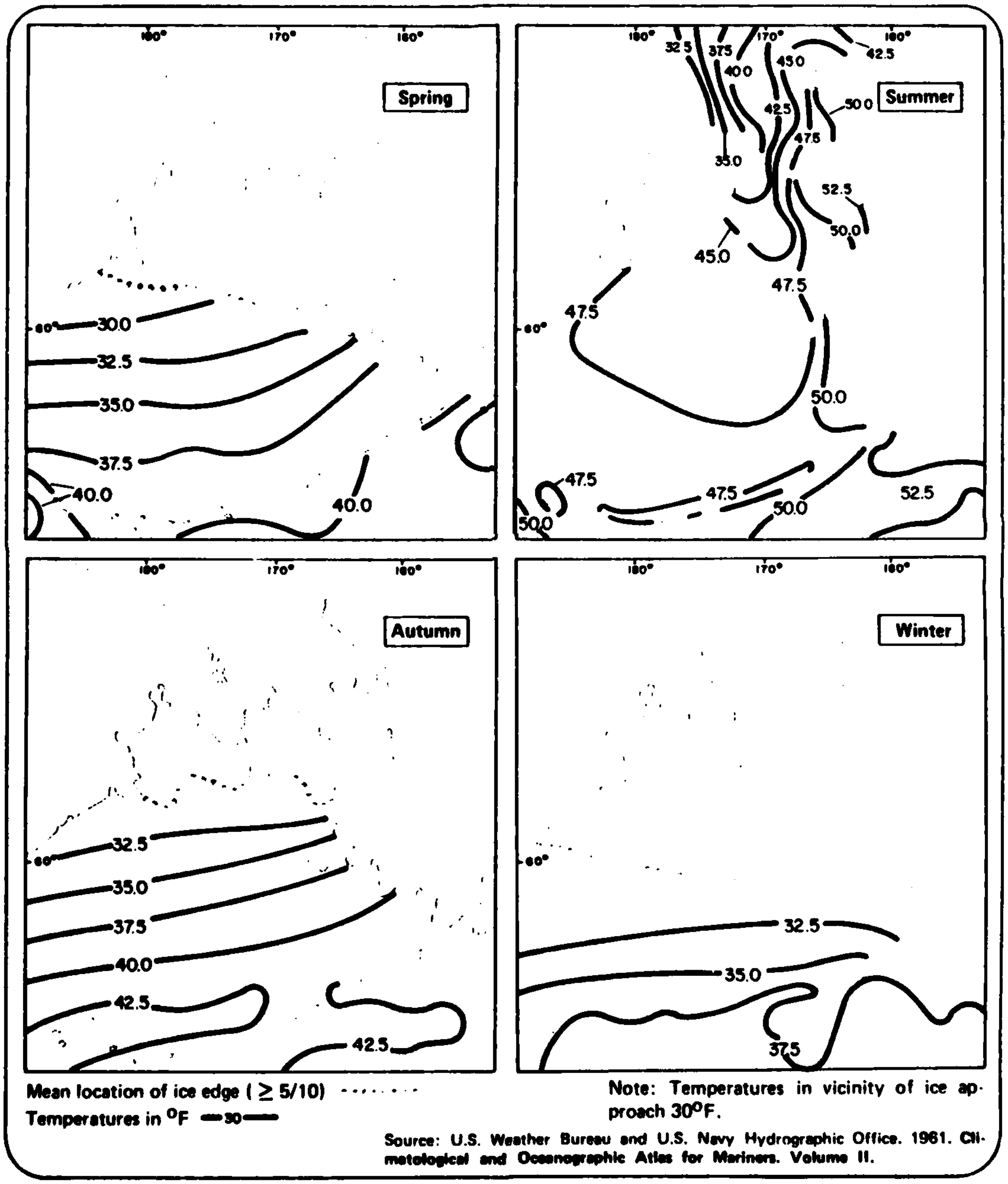
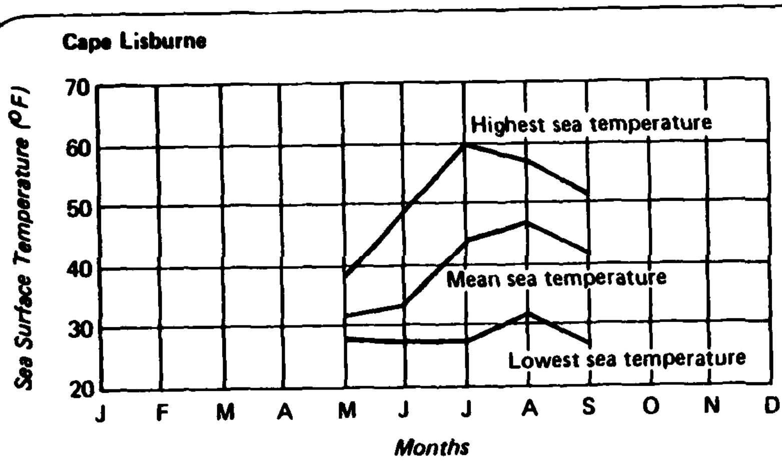
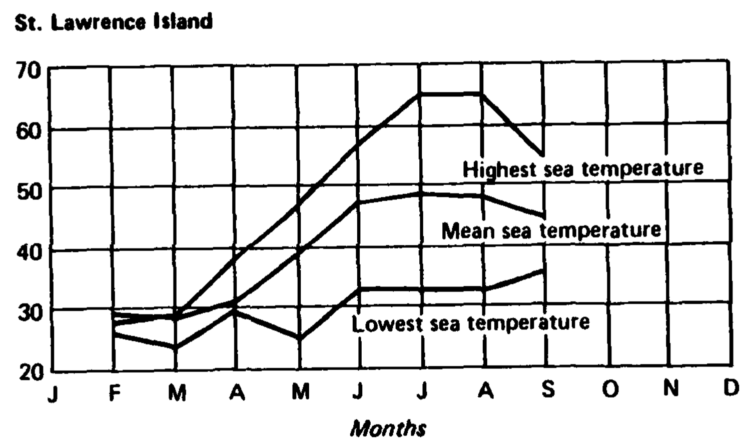


Figure 160. Seasonal sea surface temperature distribution (from Bering Sea ref. 1).



Note: Total observations = 3,098 over period 1960 to 1970. Mean annual sea surface temperature = 41.9°F. Sea is ice-covered generally from September to May.



Note: Total observations = 5,638 over period 1960 to 1970. Mean annual sea surface temperature = 40.7 °F. Sea is ice-covered generally from September to February.

Adapted from U.S. Naval Weather Service Command, 1970. **Summary of Synoptic Meterological Observations, North American Coastal Marine Areas. Volume 15.**

Figure 161. Average highest and lowest and mean sea surface temperature (from Bering Sea ref. 1).

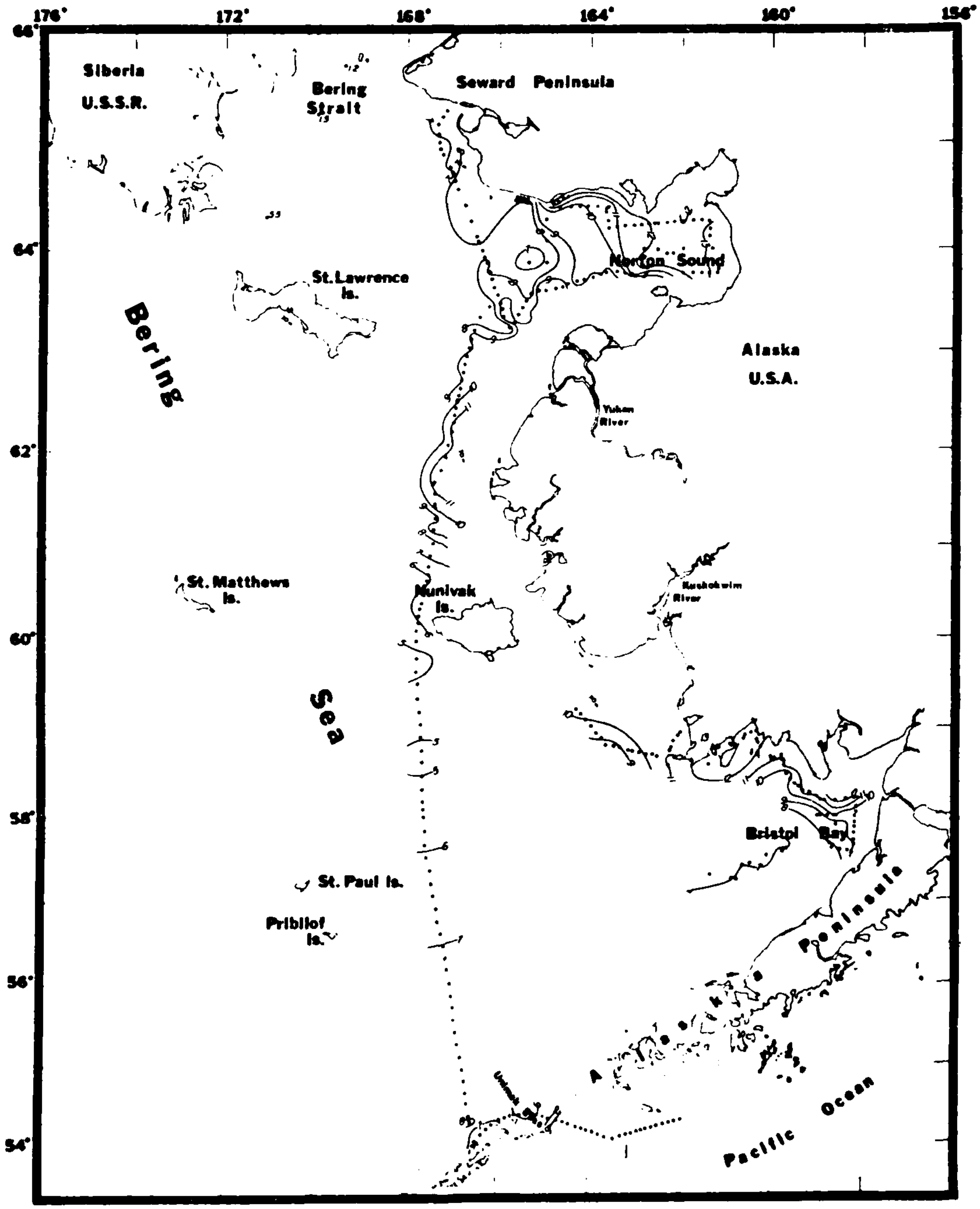


Figure 162. Surface temperature (^{o}C) in the eastern Bering Sea; 11 July-11 August 1973 (from Chukchi Sea ref. 15).

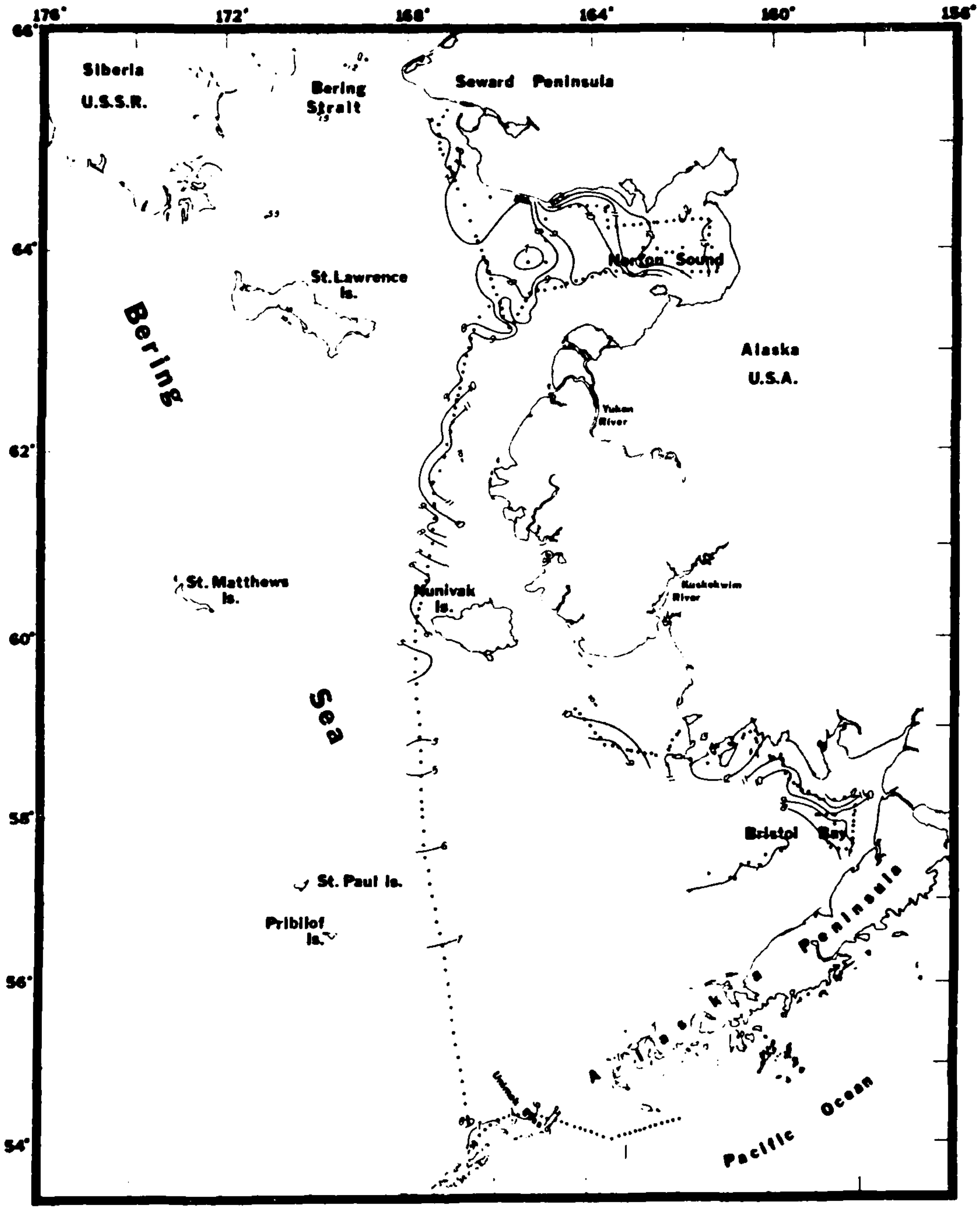
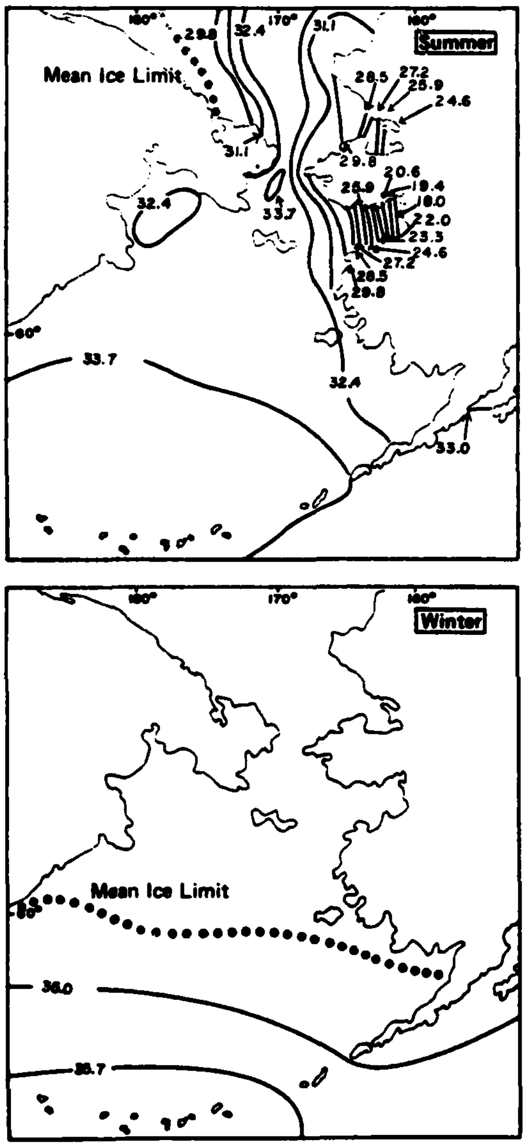


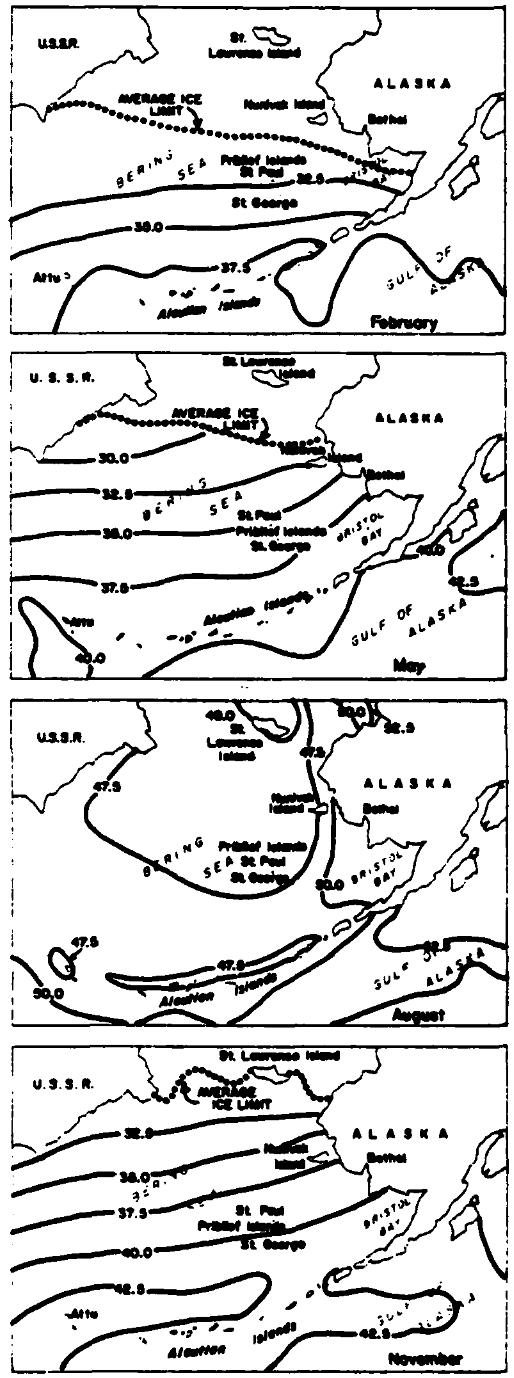
Figure 162. Surface temperature (^{o}C) in the eastern Bering Sea; 11 July-11 August 1973 (from Chukchi Sea ref. 15).



Note: Salinity values in parts per thousand are based upon mean water temperature of 15°C.

Source: U.S. Weather Bureau and U.S. Navy Hydrographic Office. 1961. Climatological and Oceanographic Atlas for Mariners. Volume II. North Pacific Ocean

Figure 163. Summer and winter surface salinity distribution (from Bering Sea ref. 1).



Source: U.S. Navy Hydrographic Office, 1961. Climatological and Oceanographic Atlas for Mariners. Vol. II

Figure 164. Sea temperatures in the Bering Sea in Degrees Fahrenheit (from Bering Sea ref. 1).

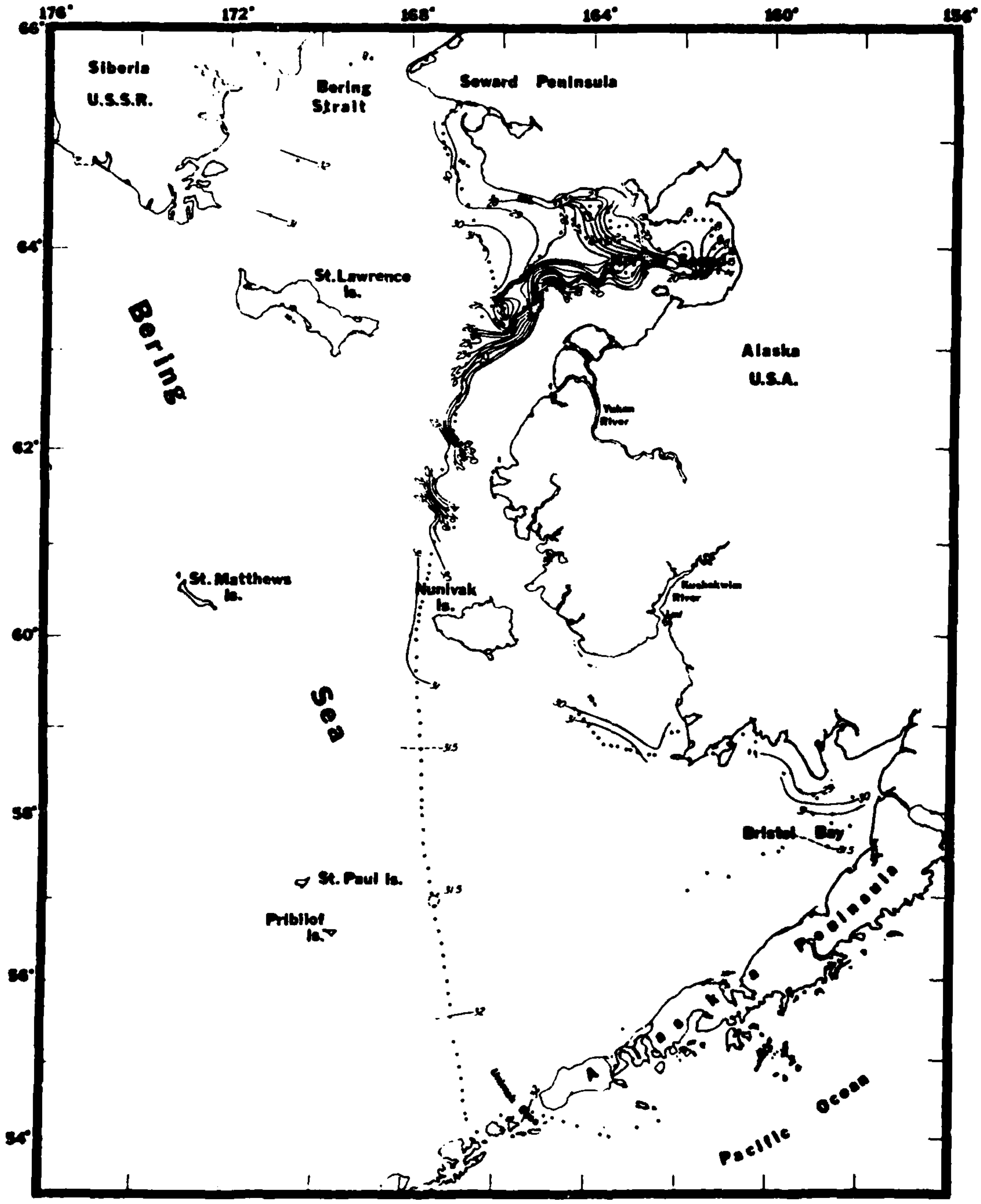


Figure 165. Surface salinity (0/00) in the eastern Bering Sea; 11 July-11 August 1973 (from Chukchi Sea ref. 15).

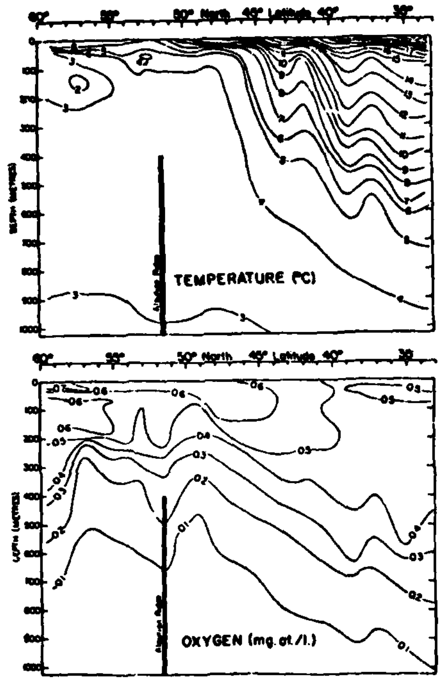


Figure 166. Vertical sections of salinity, temperature and dissolved oxygen along longitude 180 (from Bering Sea ref. 17).

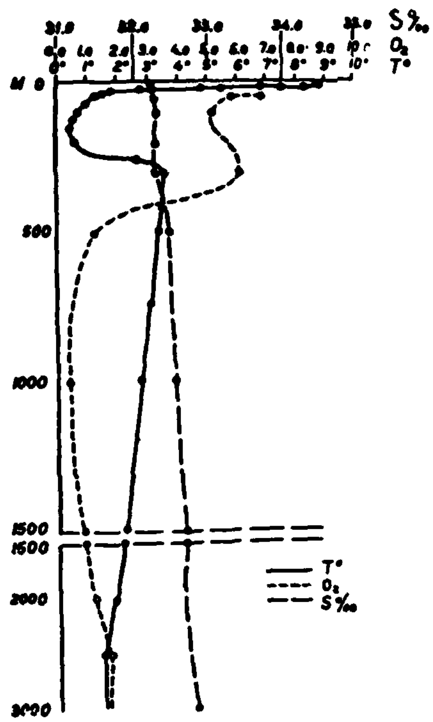
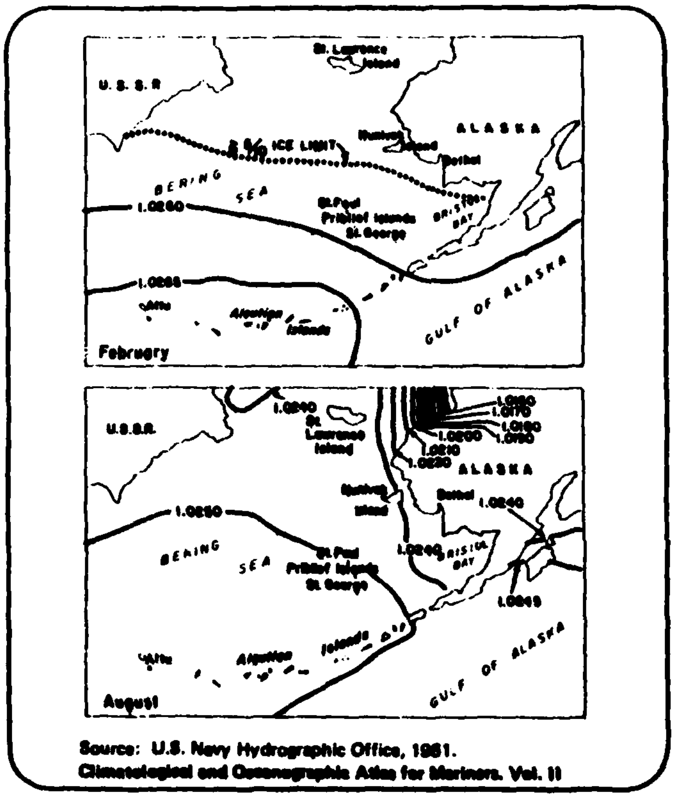


Figure 167. Vertical distribution of temperature (continuous line), oxygen (short dashes), and salinity (from Bering Sea ref. 17).

Figure 168. Density distribution of water in the Bering Sea (from Bering Sea ref. 1).



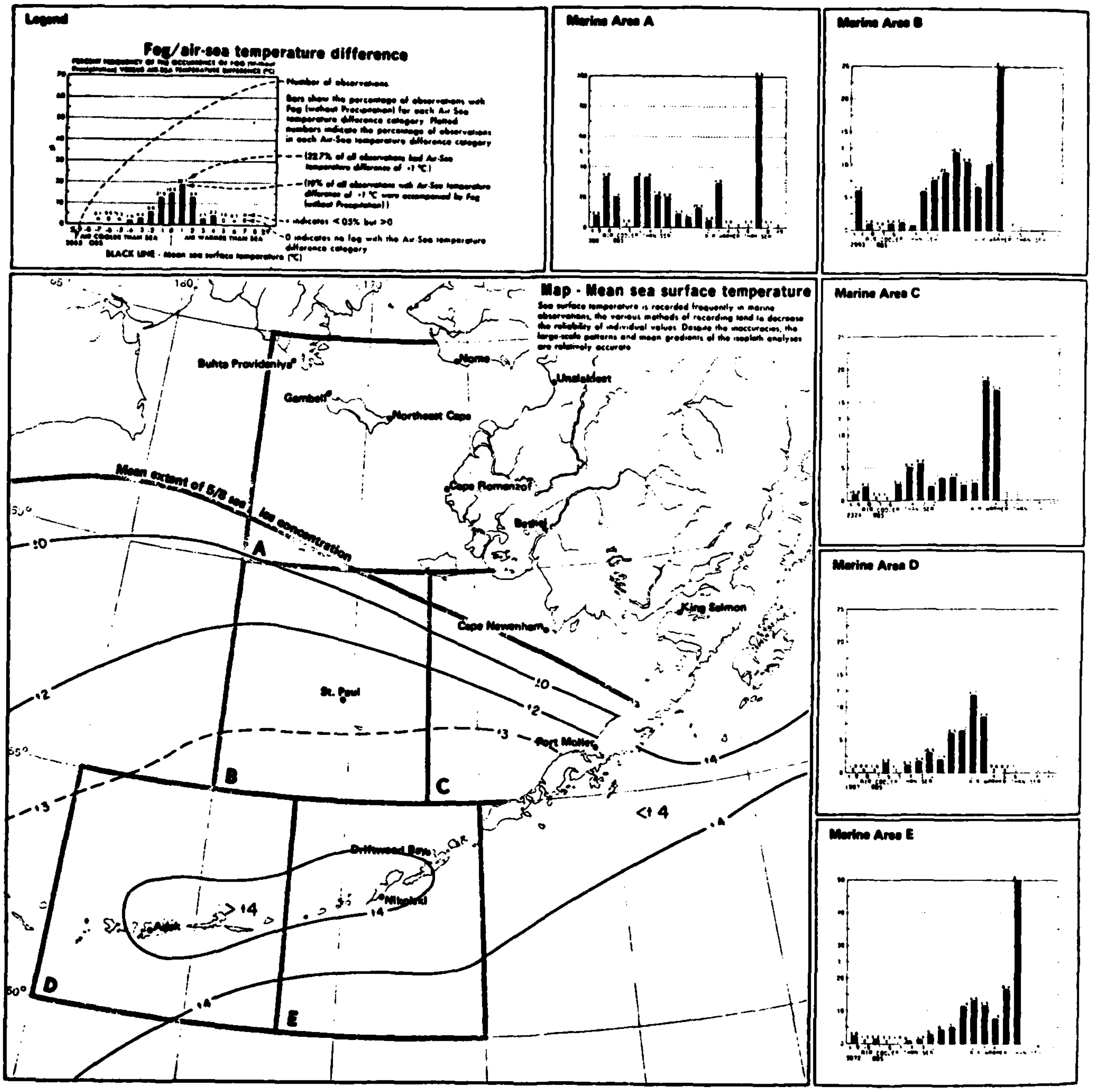


Figure 169. Fog/air-sea temperature difference, mean sea surface temperature, January (from Bering Sea ref. 2).

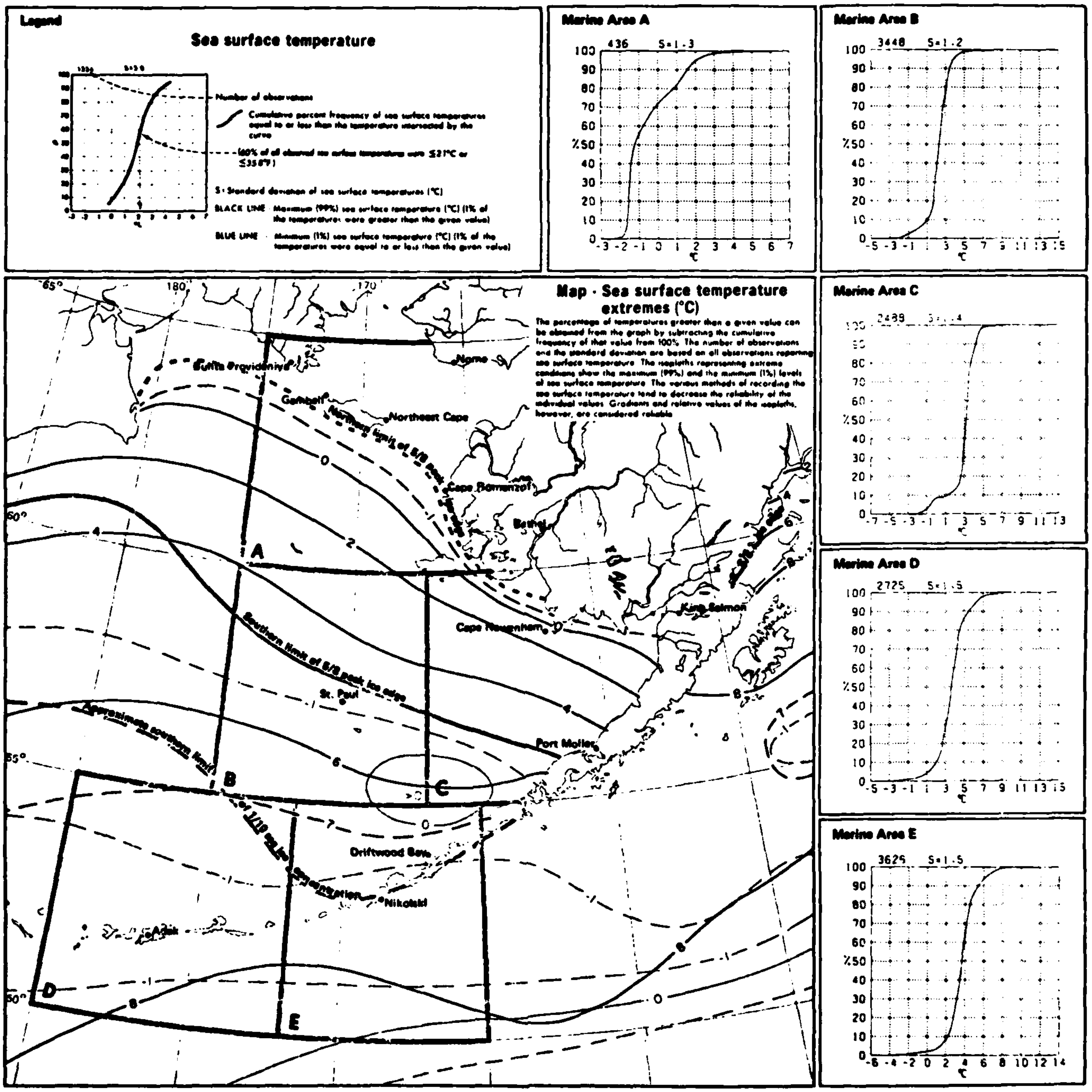


Figure 170. Sea surface temperature extremes, January (from Bering Sea ref. 2).

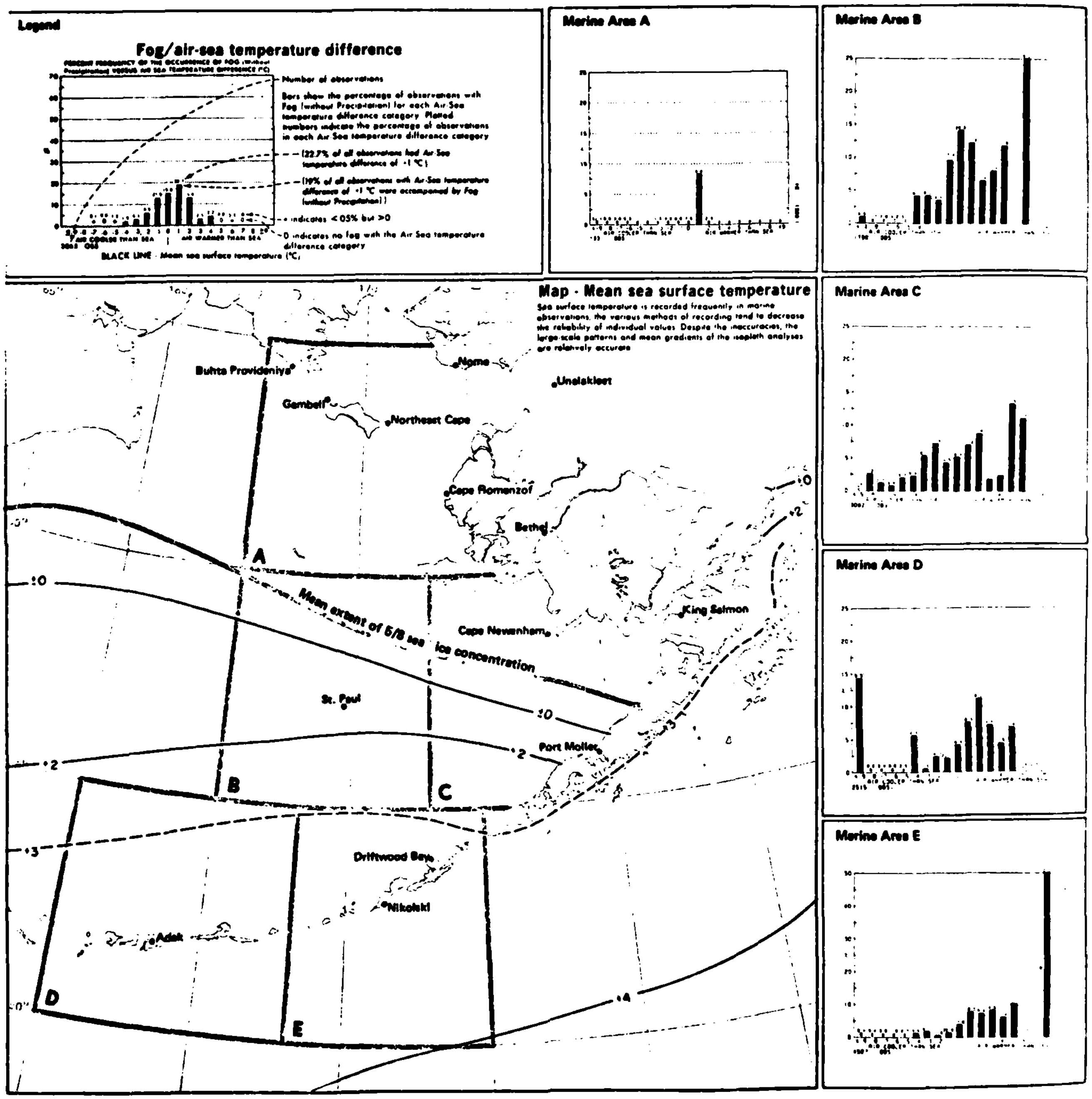


Figure 171. Fog/air-sea temperature difference, mean sea surface temperature, February (from Bering Sea ref. 2).

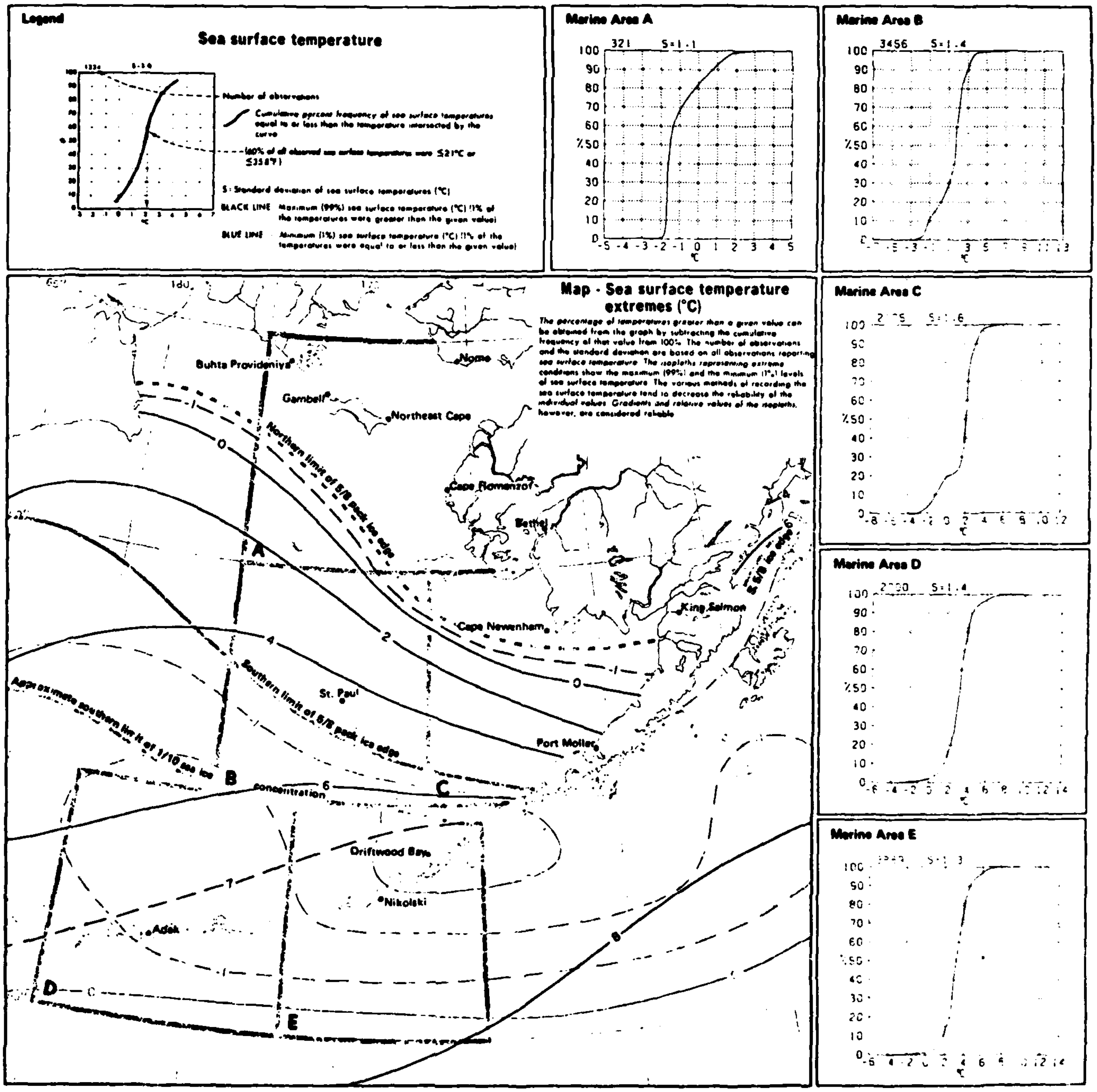


Figure 172. Sea surface temperature extremes, February (from Bering Sea ref. 2).

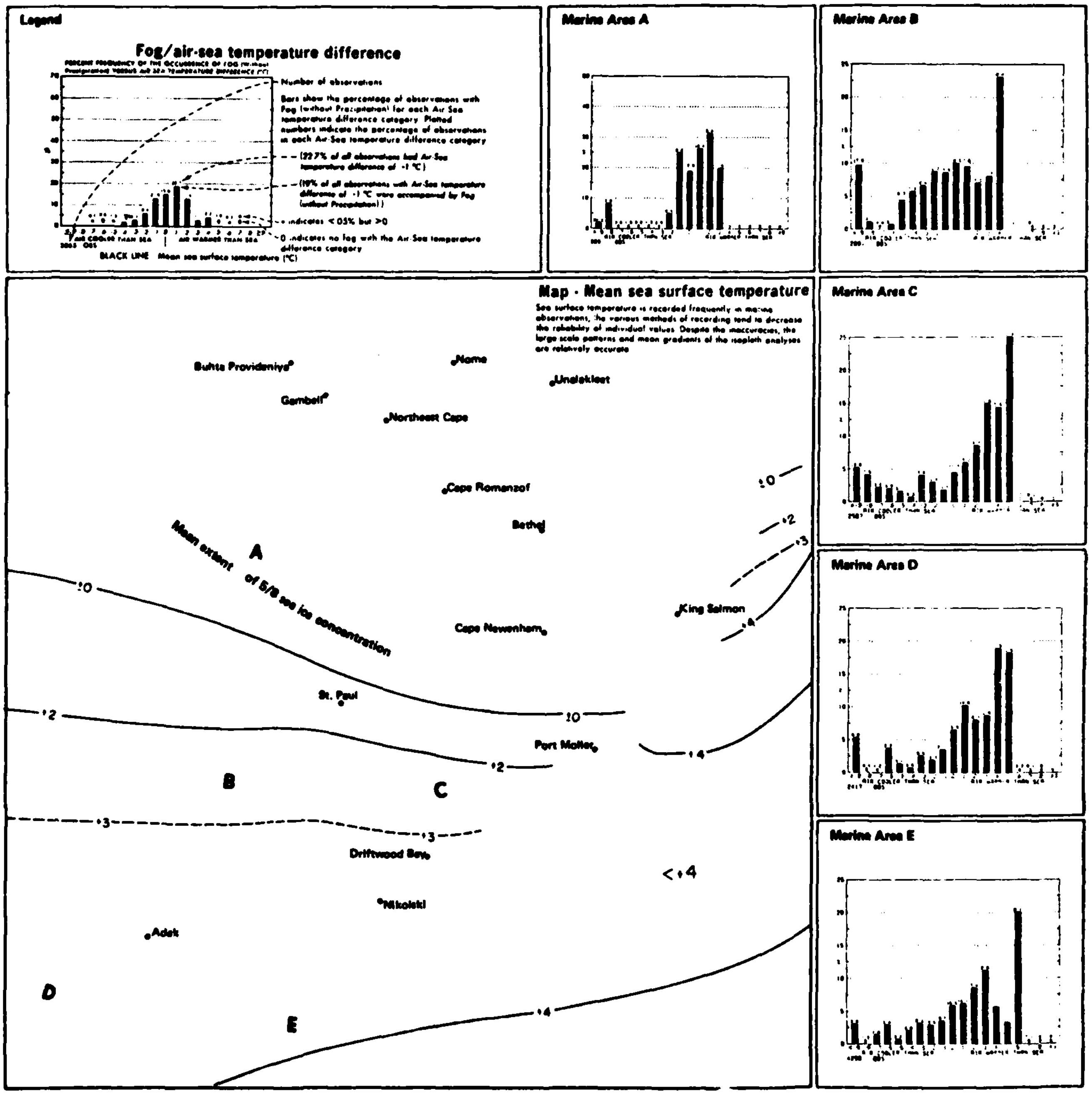


Figure 173. Fog/air-sea temperature difference, mean sea surface temperature, March (from Bering Sea ref. 2).

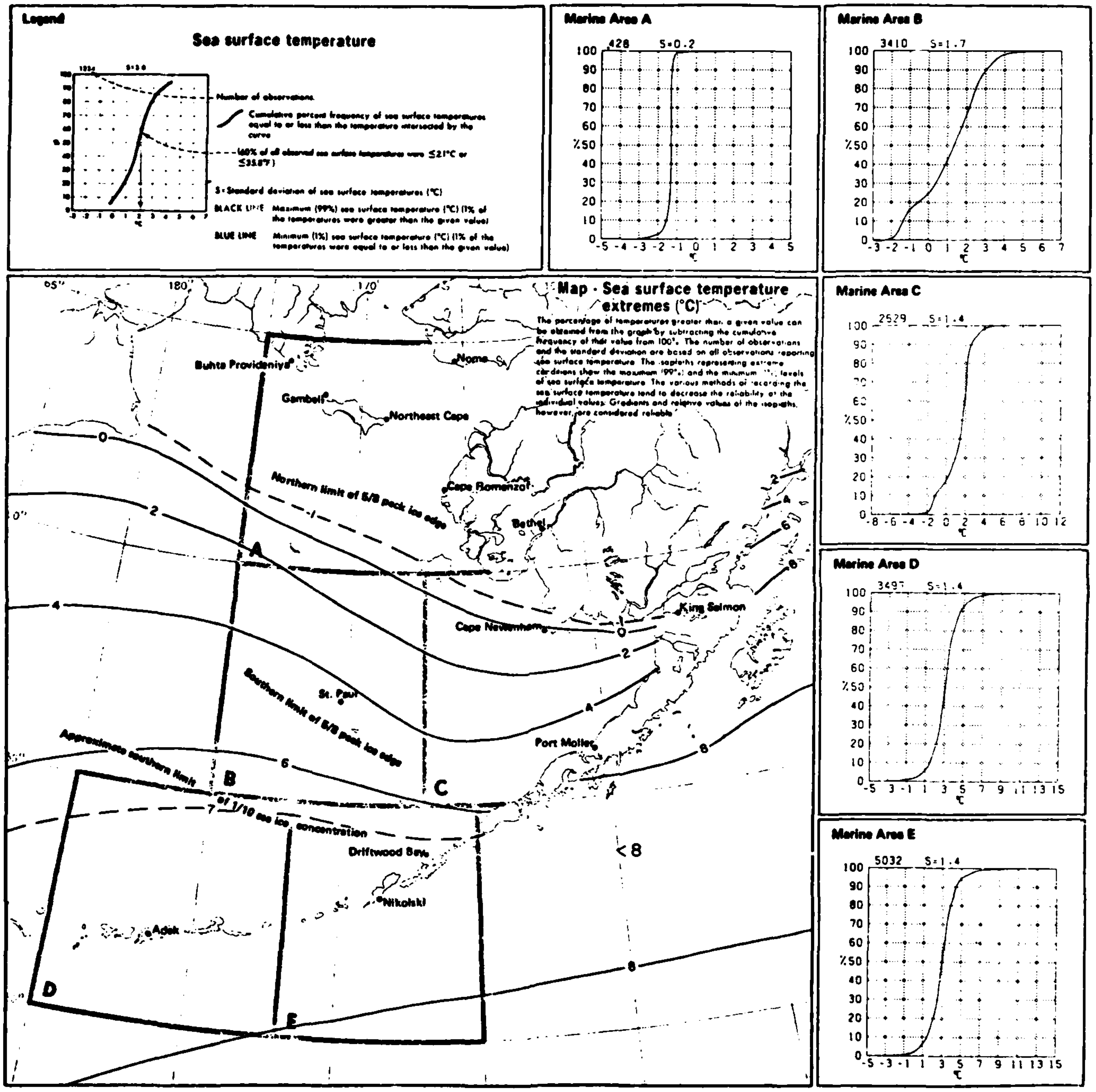


Figure 174. Sea surface temperature extremes, March (from Bering Sea ref. 2).

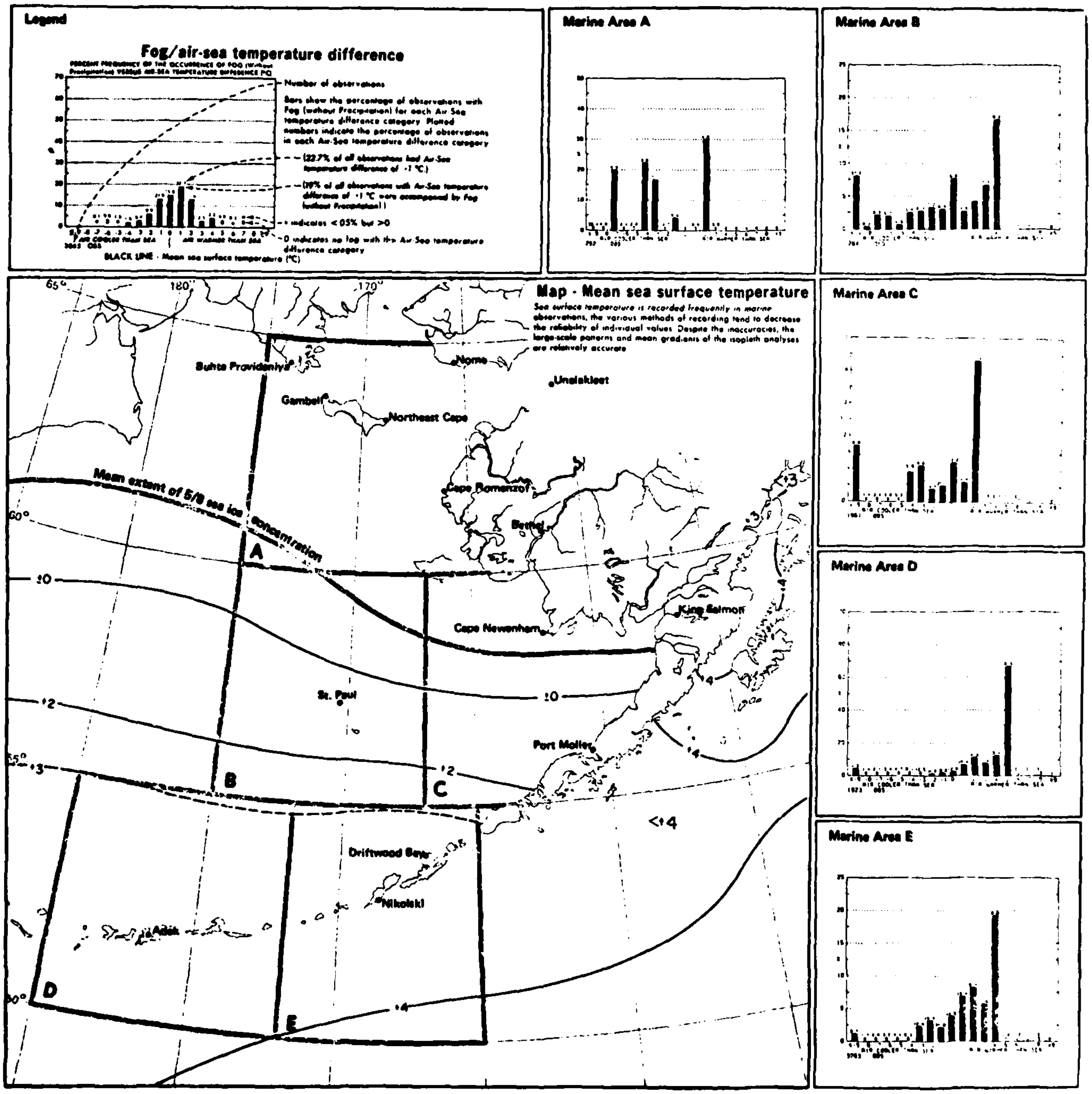


Figure 175. Fog/air-sea temperature difference, mean sea surface temperature, April (from Bering Sea ref. 2).

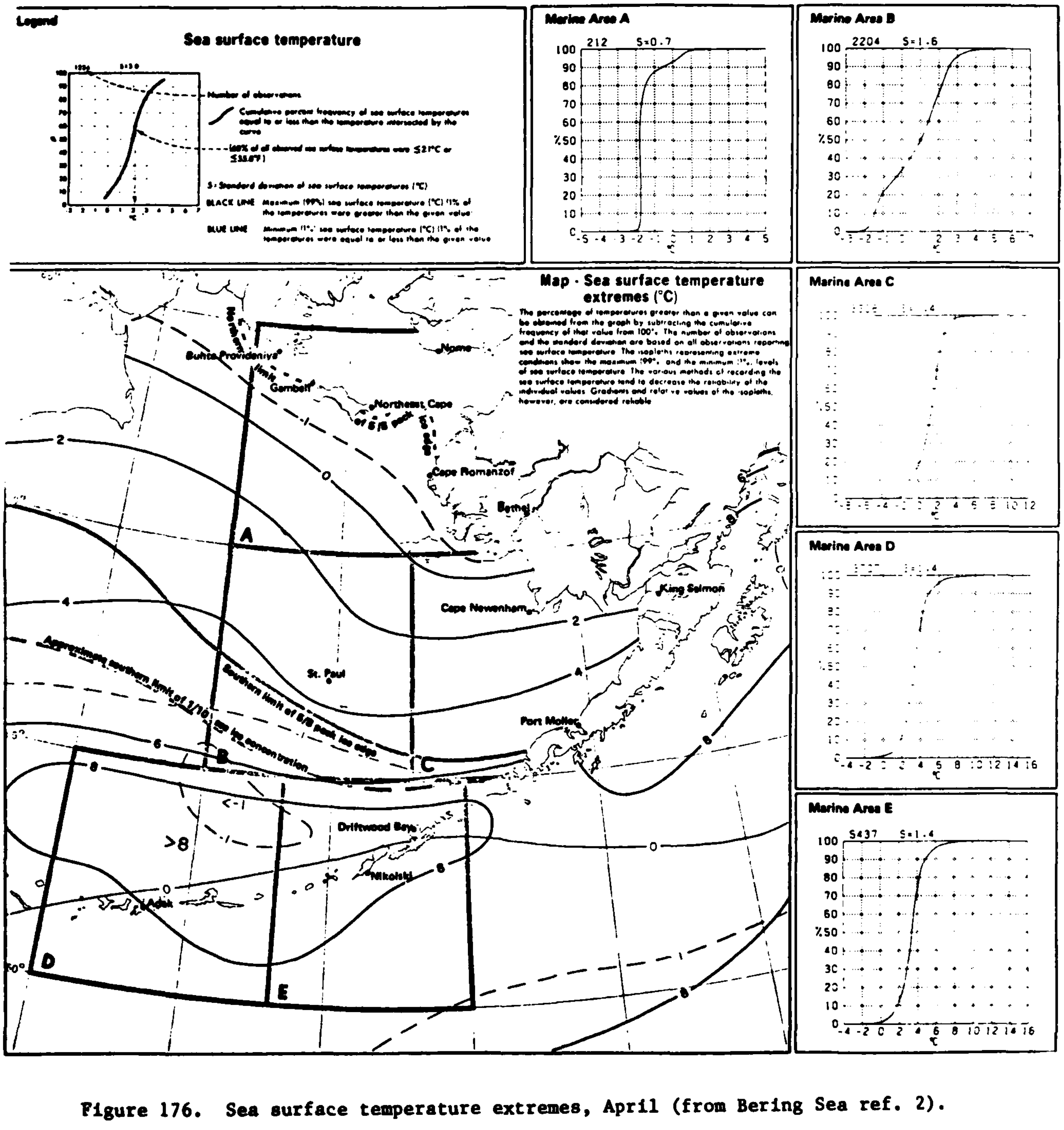


Figure 176. Sea surface temperature extremes, April (from Bering Sea ref. 2).

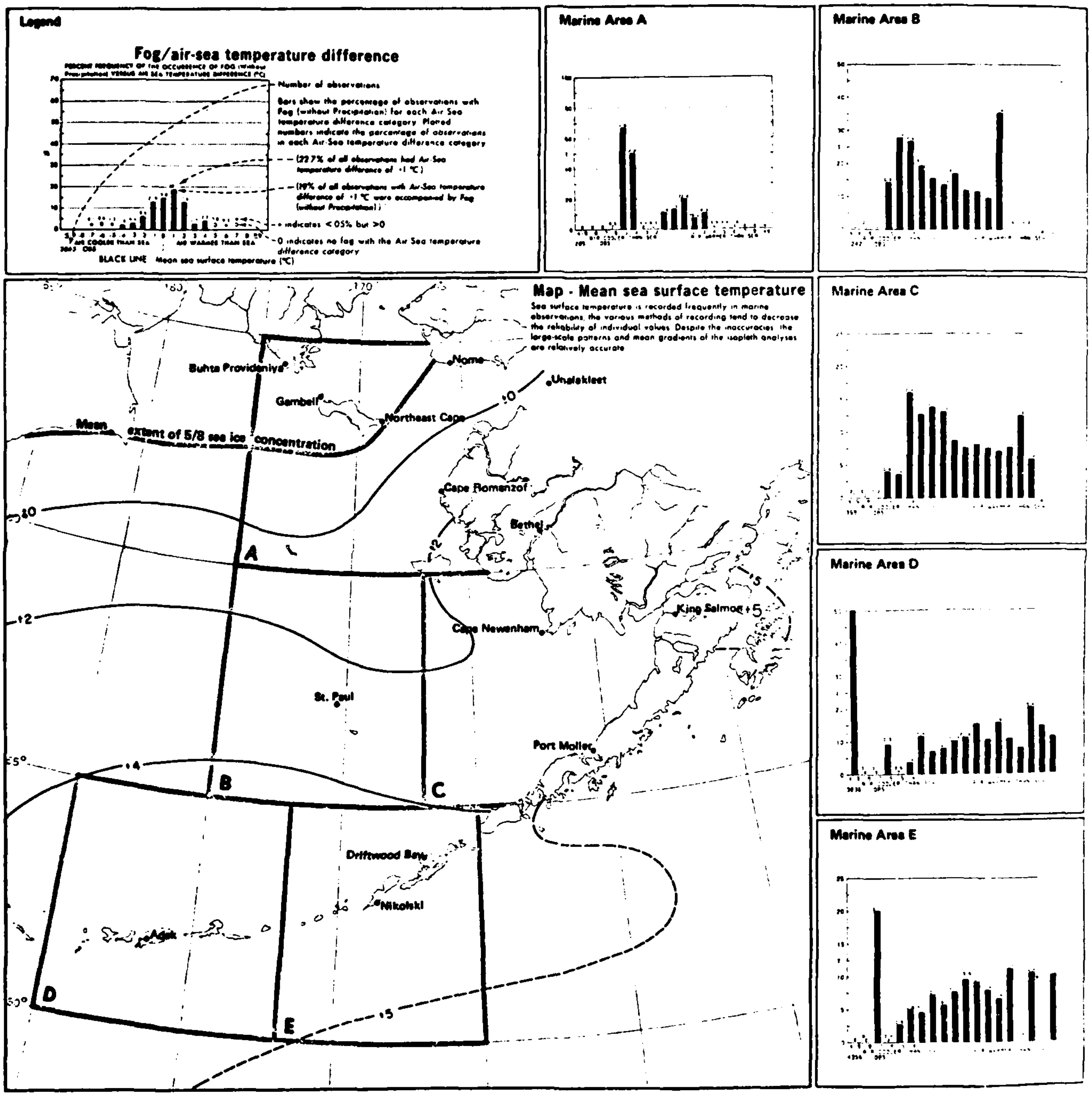


Figure 177. Fog/air-sea temperature difference, mean sea surface temperature, May (from Bering Sea ref. 2).

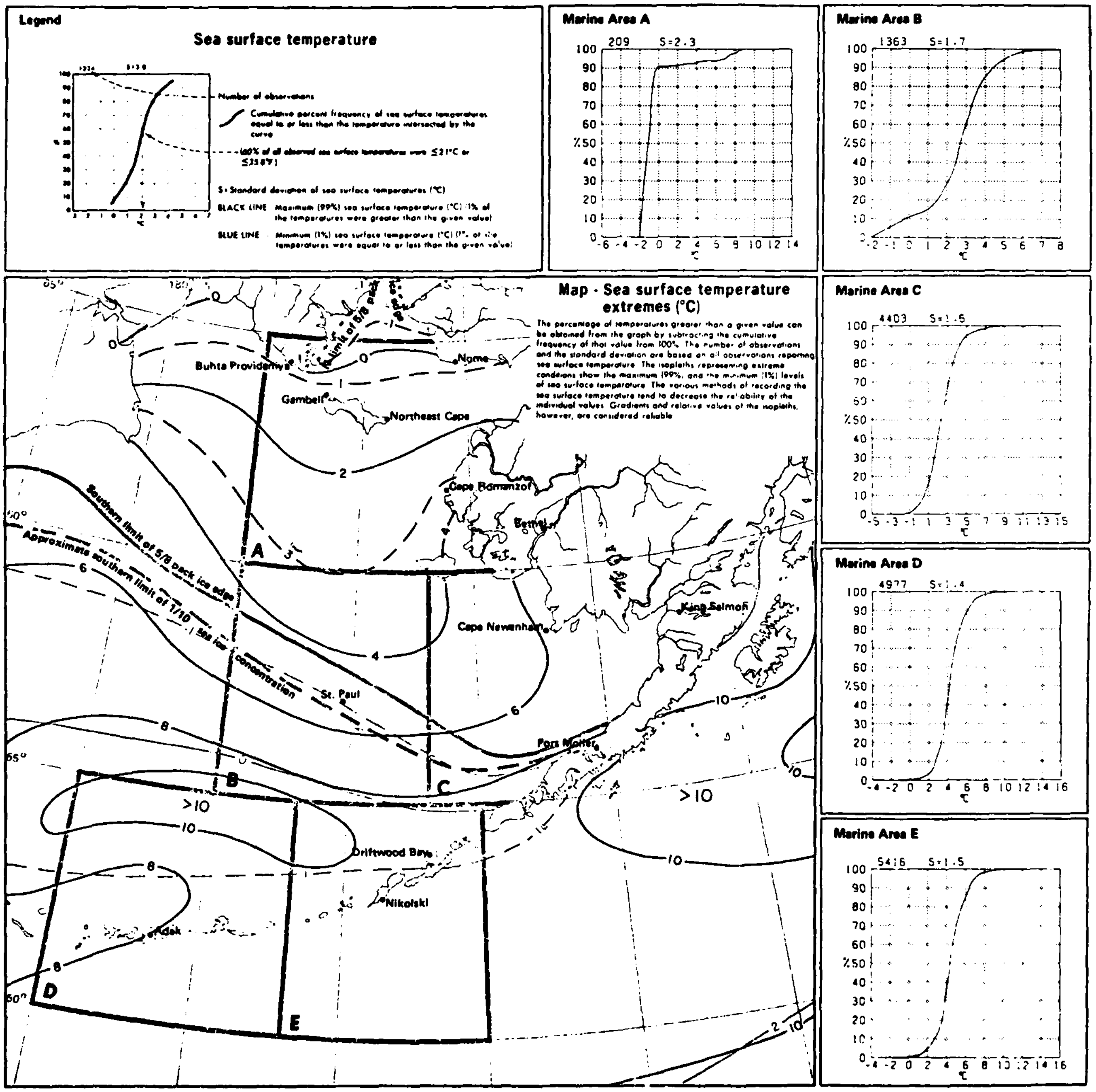


Figure 178. Sea surface temperature extremes, May (from Bering Sea ref. 2).

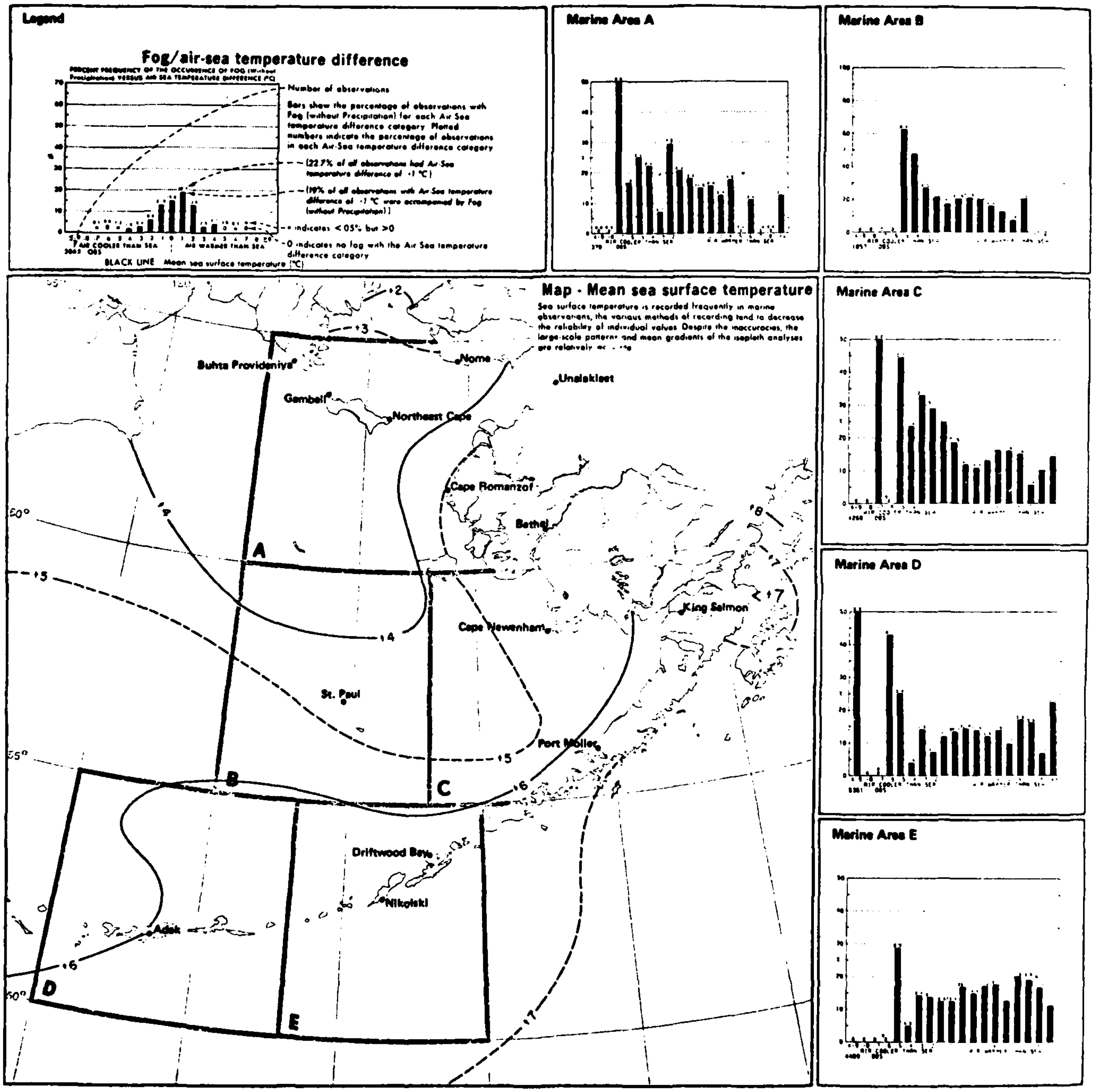


Figure 179. Fog/air-sea temperature difference, mean sea surface temperature, June (from Bering Sea ref. 2).

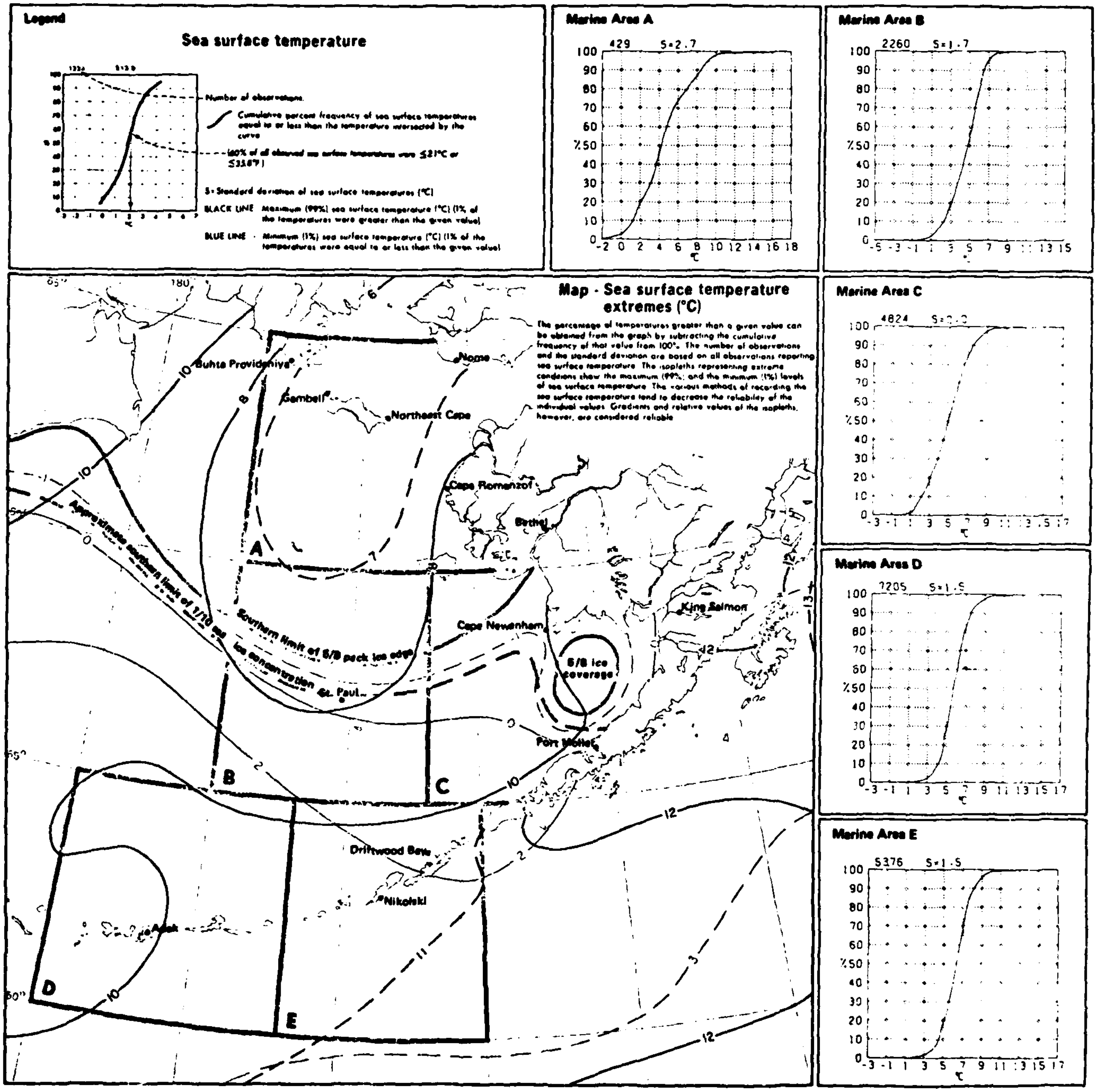


Figure 180. Sea surface temperature extremes, June (from Bering Sea ref. 2).

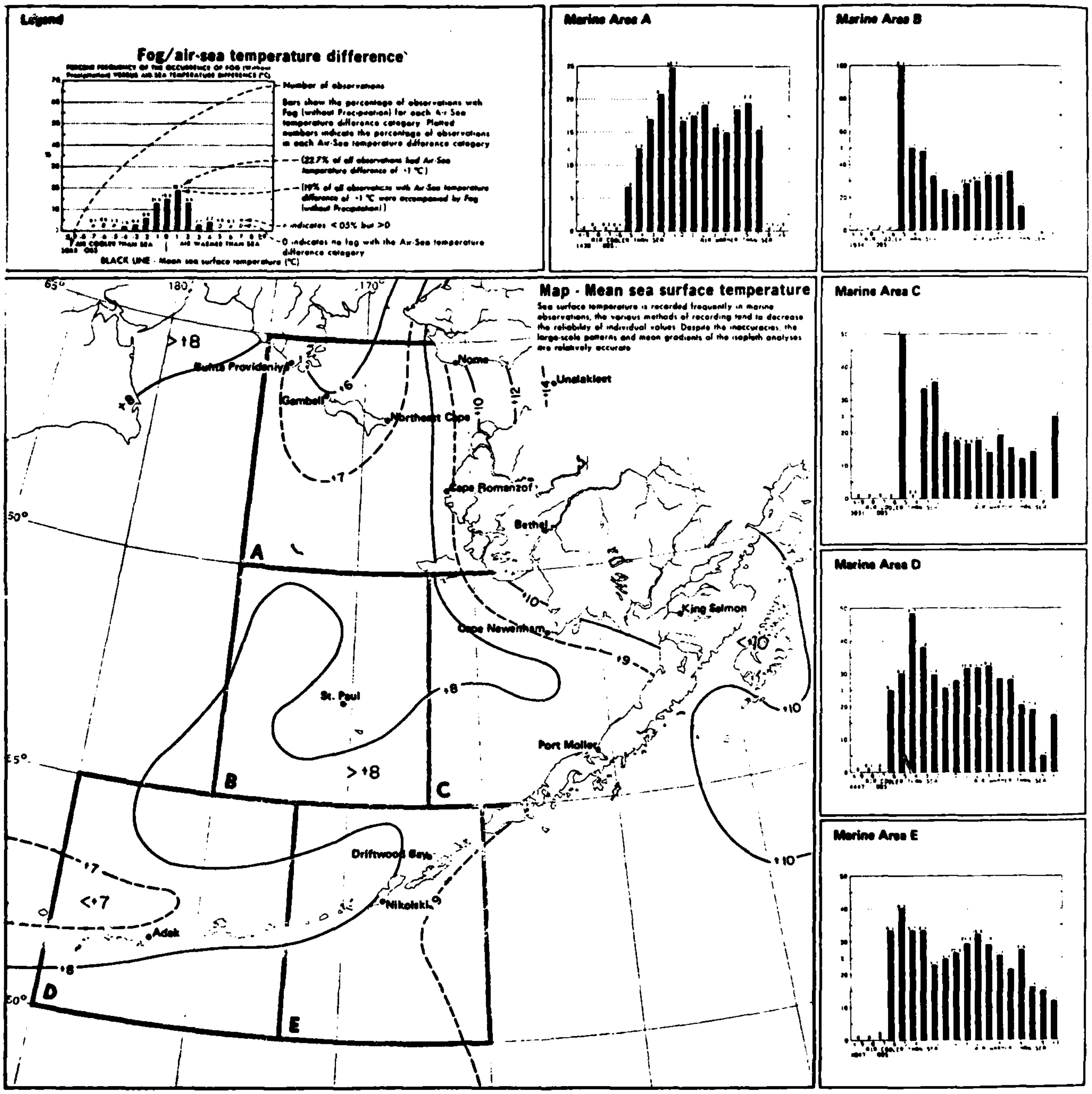


Figure 181. Fog/air-sea temperature difference, mean sea surface temperature, July (from Bering Sea ref. 2).

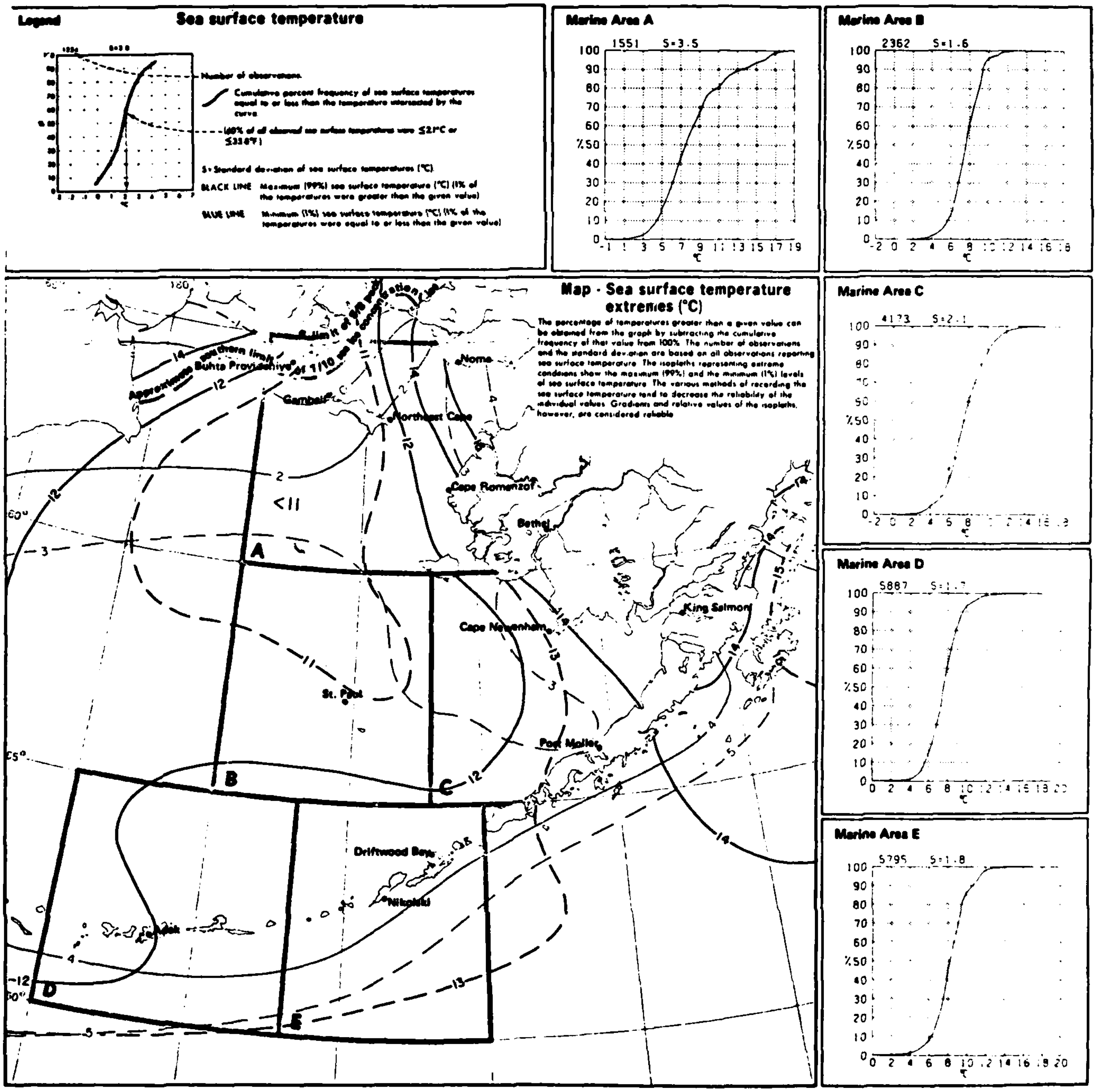


Figure 182. Sea surface temperature extremes, July (from Bering Sea ref. 2).

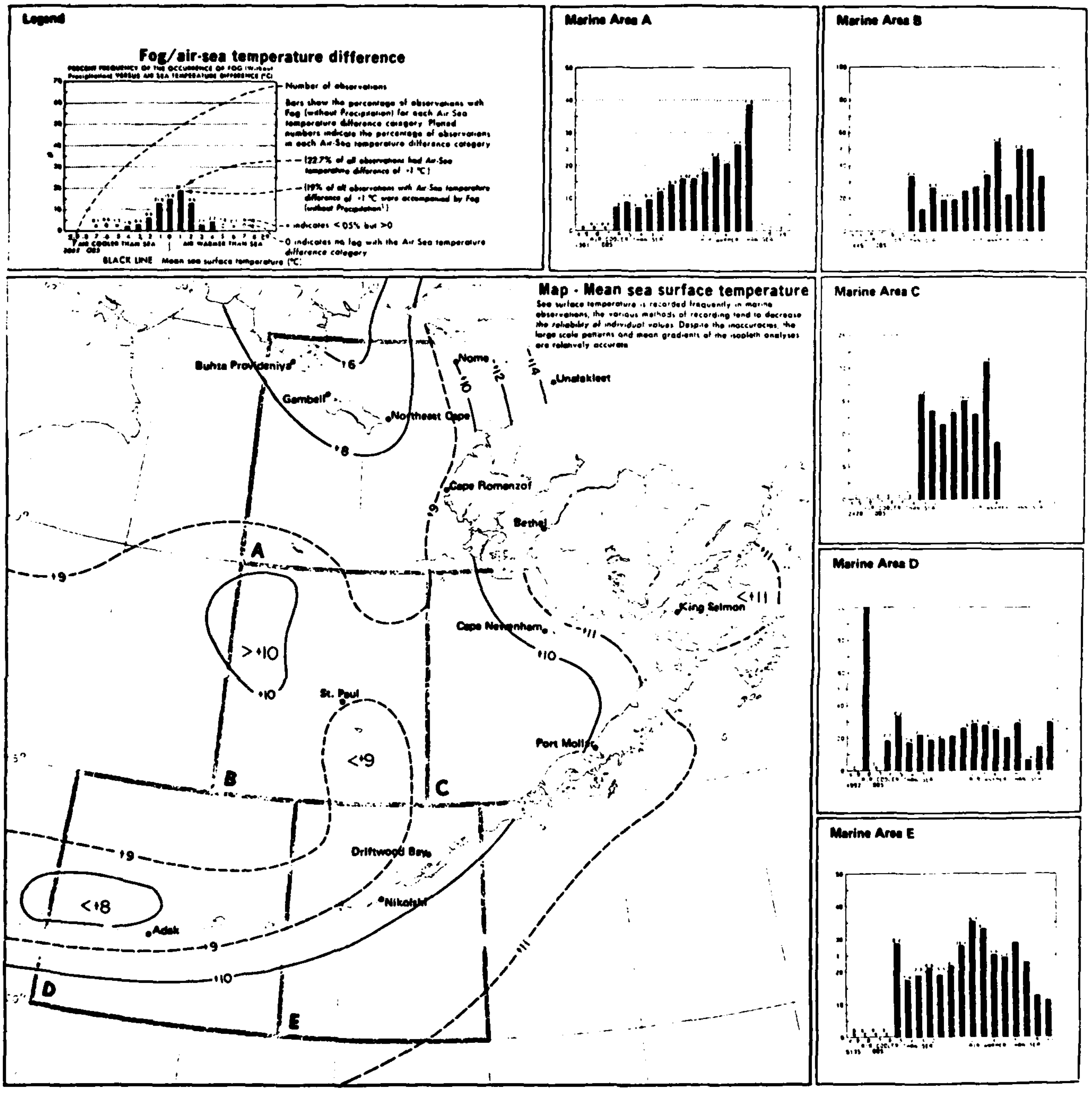


Figure 183. Fog/air-sea temperature difference, mean sea surface temperature, August (from Bering Sea ref. 2).

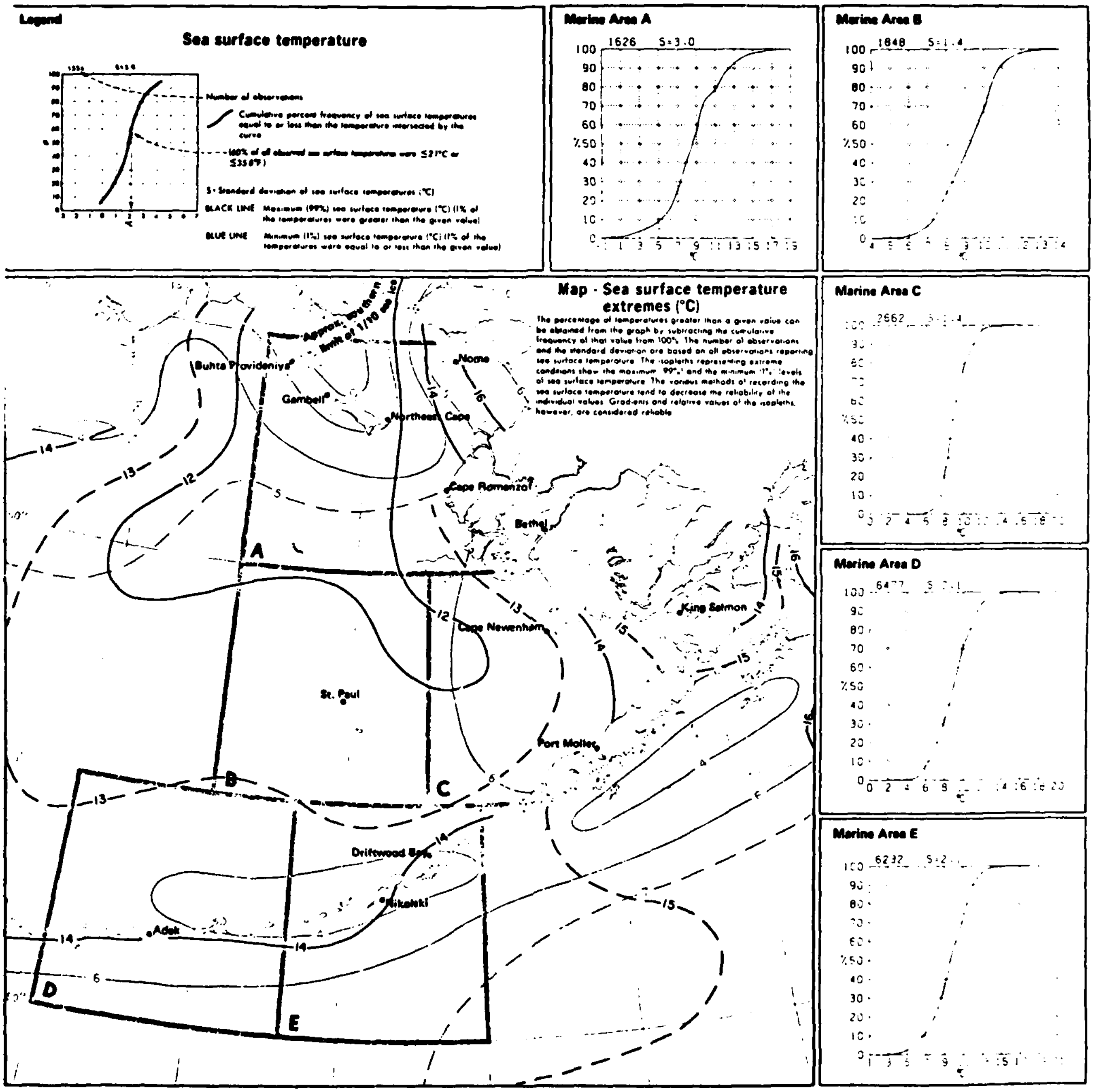


Figure 184. Sea surface temperature extremes, August (from Bering Sea ref. 2).

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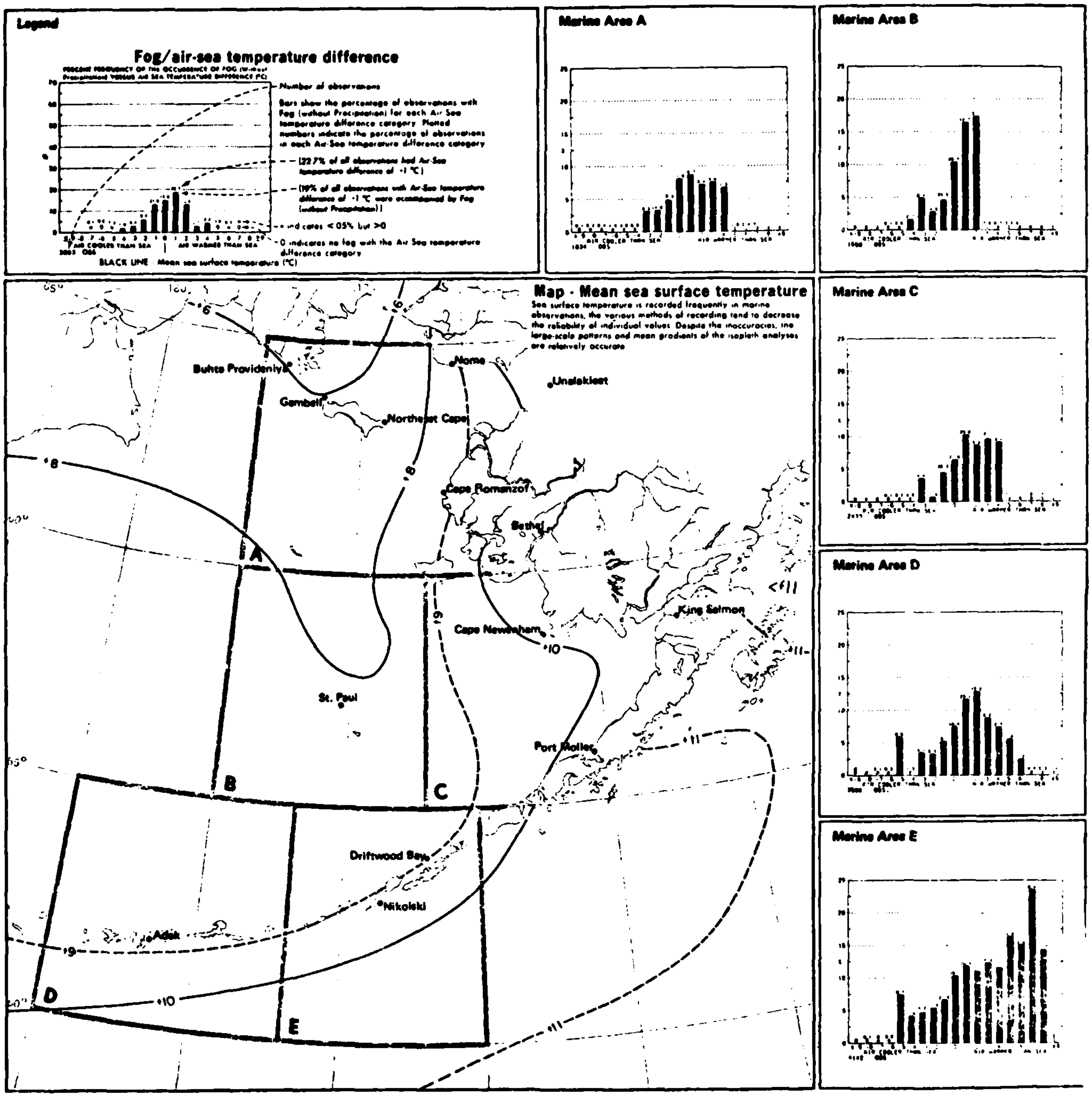

Figure 185. Fog/air-sea temperature difference, mean sea surface temperature, September (from Bering Sea ref. 2).

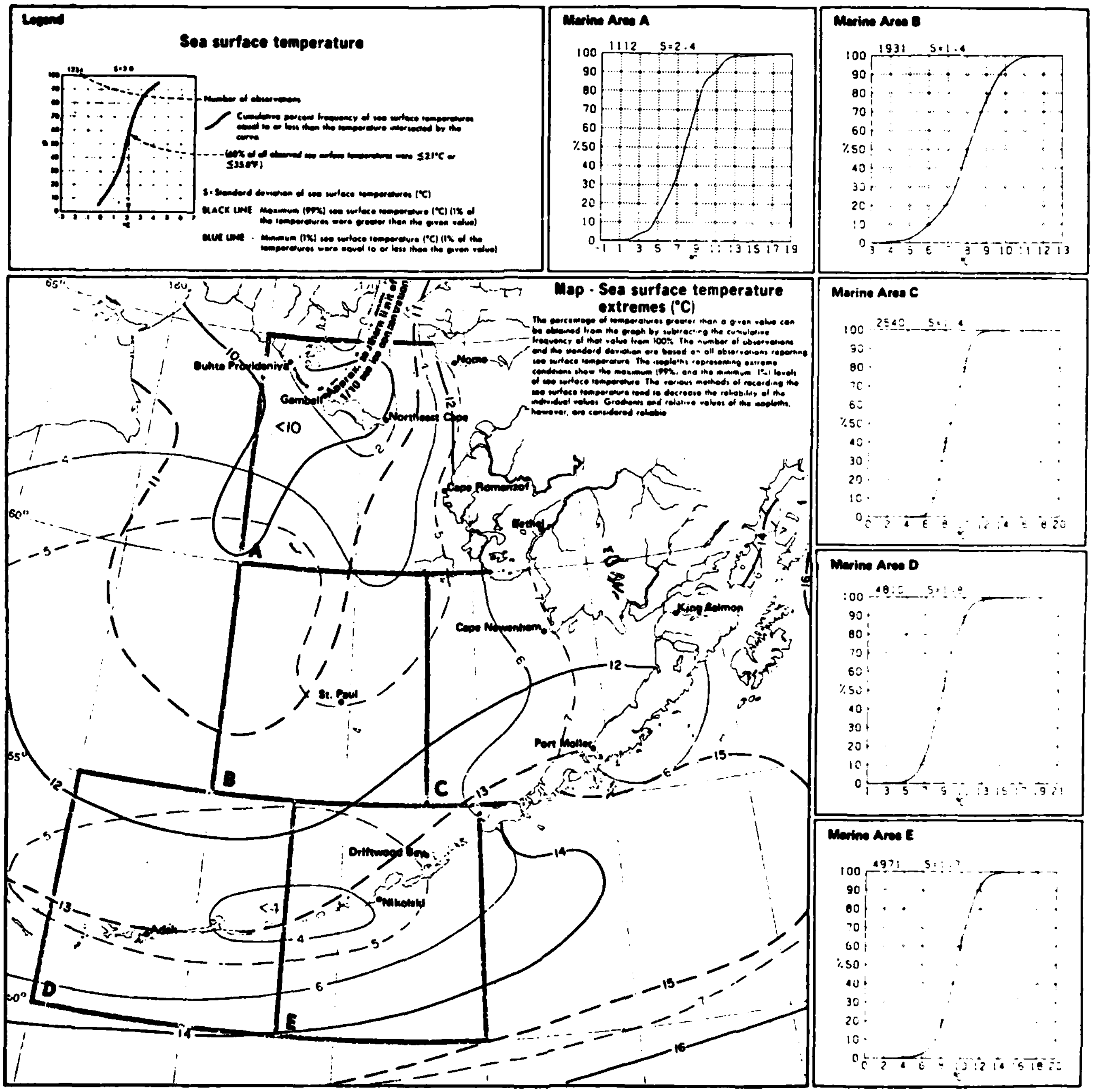

Figure 186. Sea surface temperature extremes, September (from Bering Sea ref. 2).

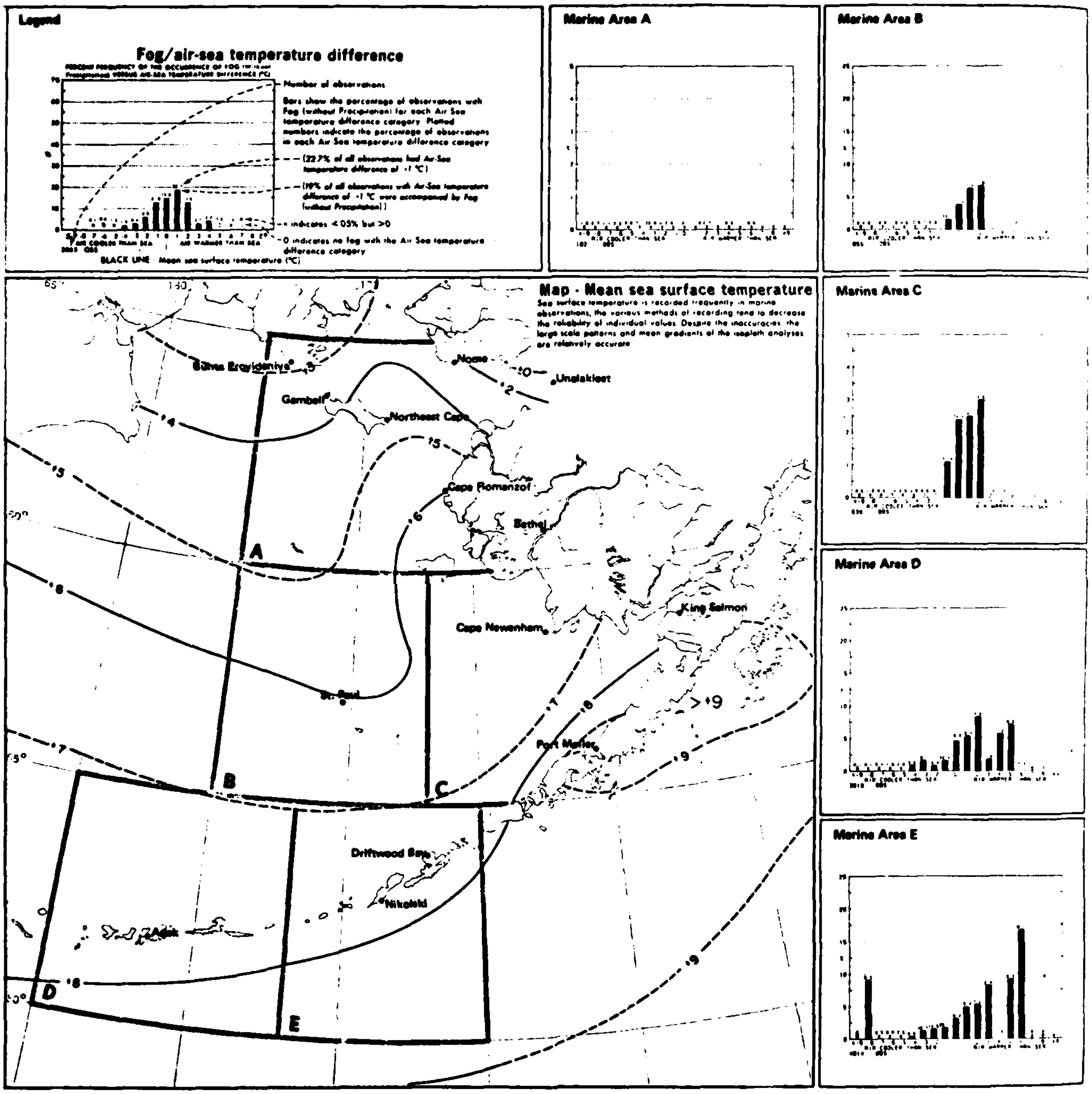

Figure 187. Fog/air-sea temperature difference, mean sea surface temperature, October (from Bering Sea ref. 2).

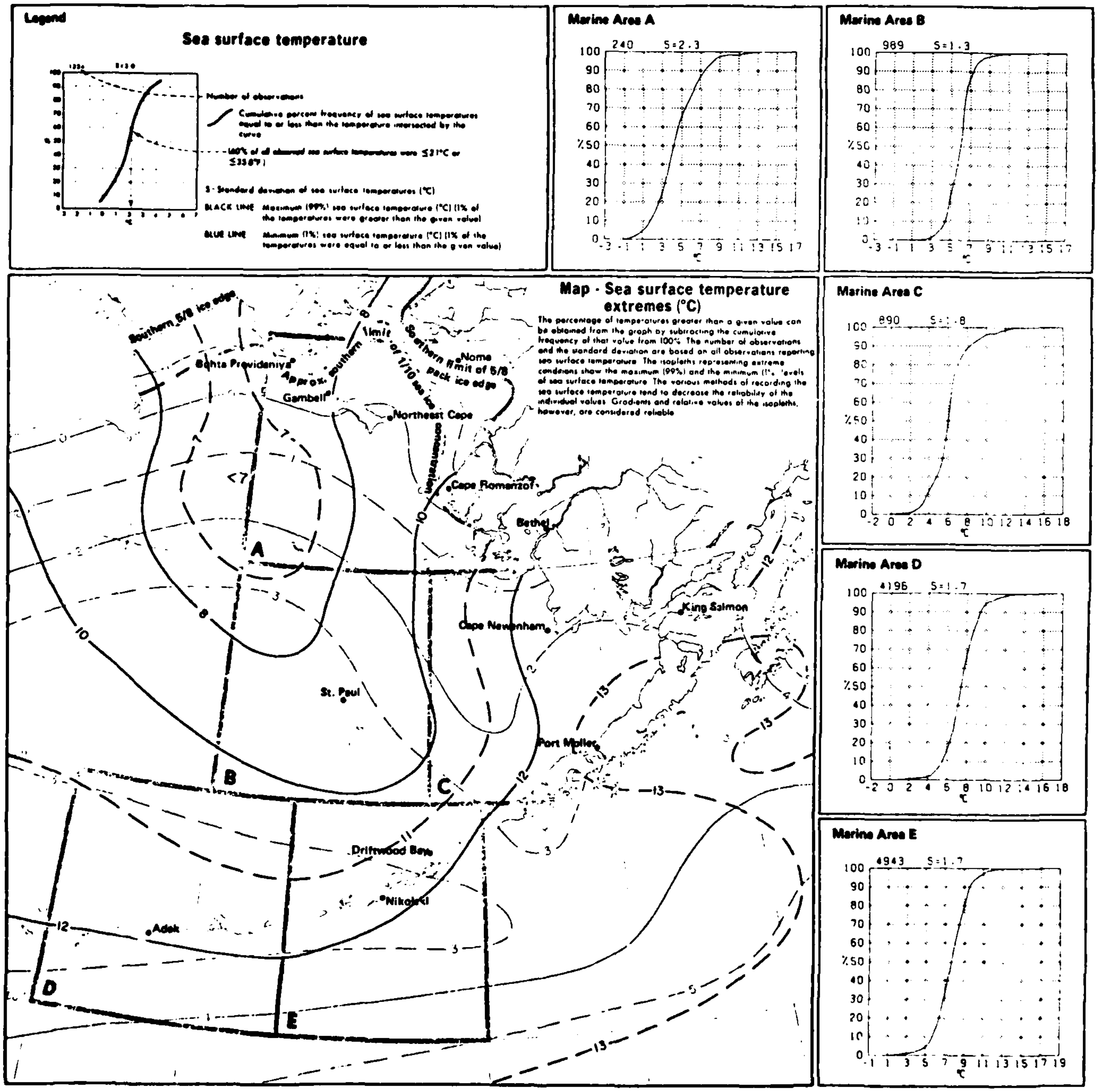

Figure 188. Sea surface temperature extremes, October (from Bering Sea ref. 2).

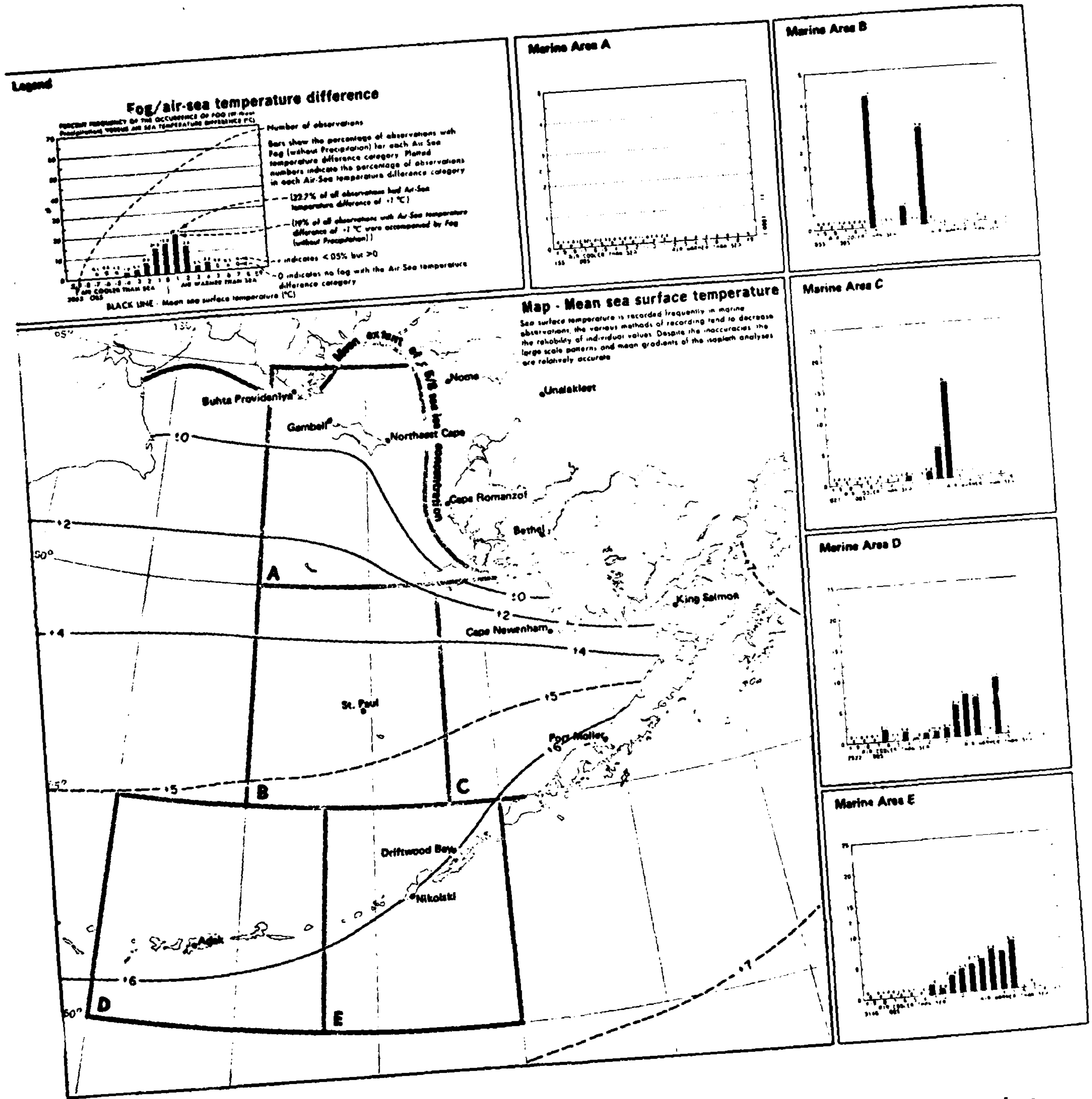

Figure 189. Fog/air-sea temperature difference, mean sea surface temperature, November (from Bering Sea ref. 2).

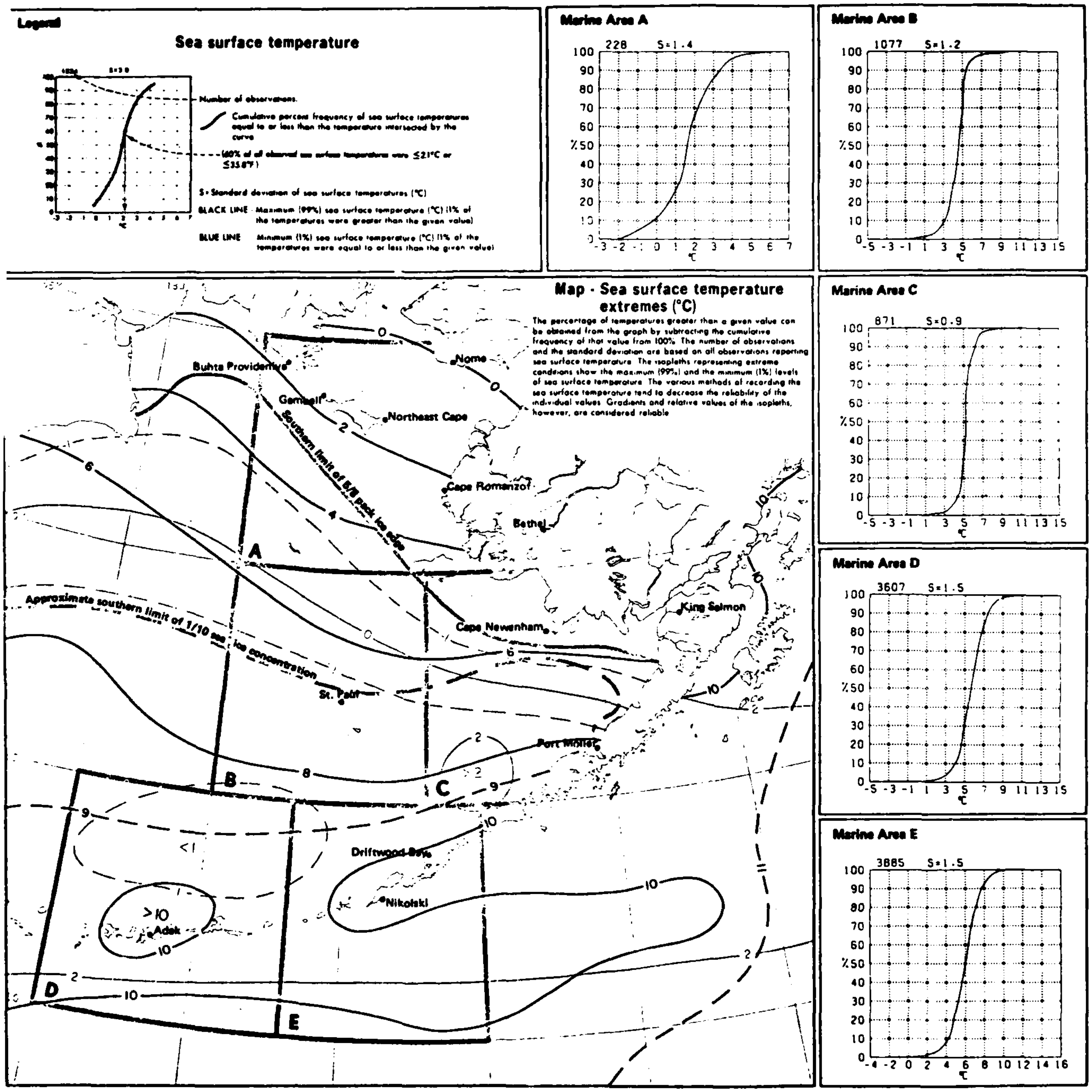

Figure 190. Sea surface temperature extremes, November (from Bering Sea ref. 2).

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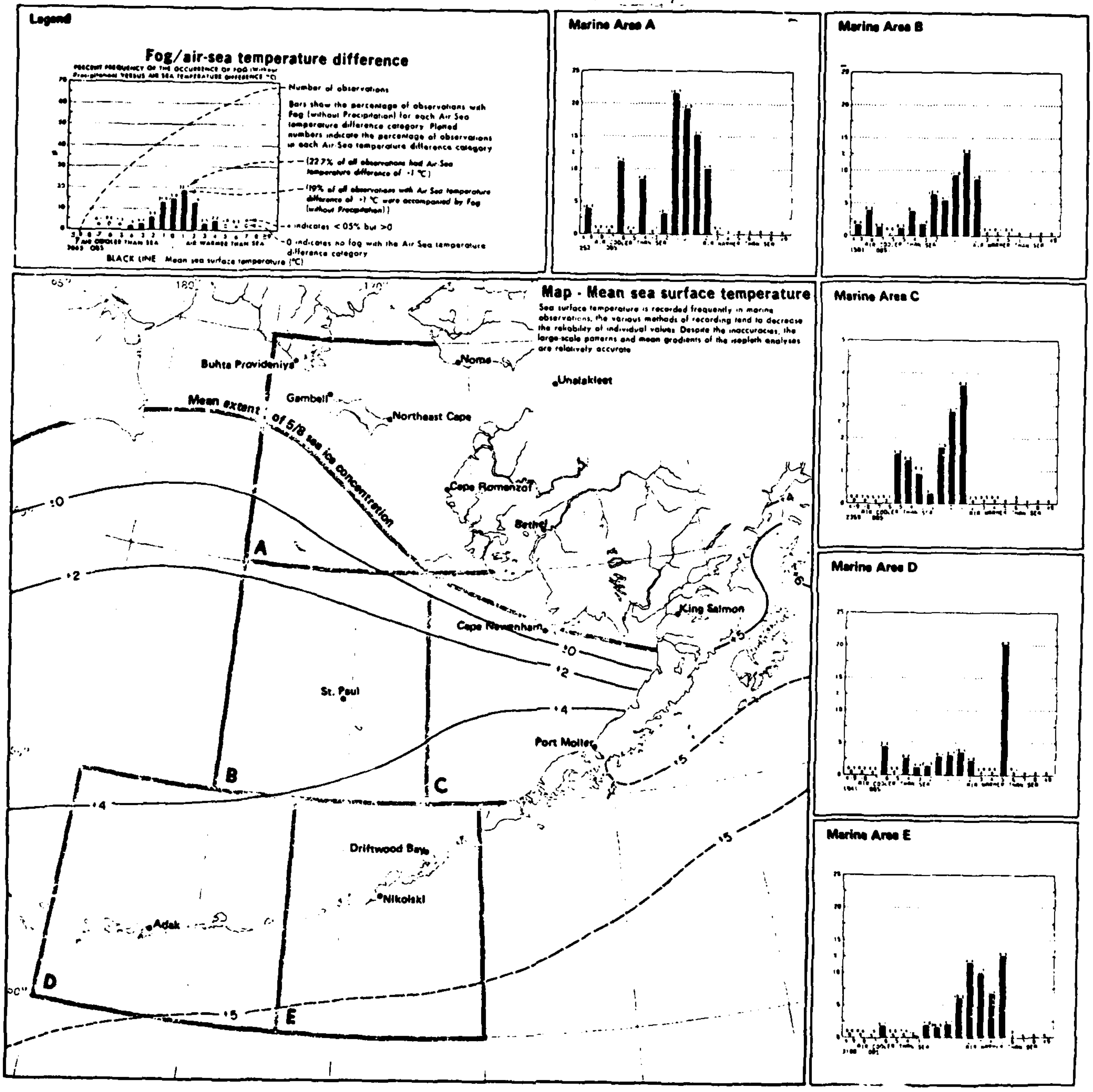

Figure 191. Fog/air-sea temperature difference, mean sea surface temperature, December (from Bering Sea ref. 2).

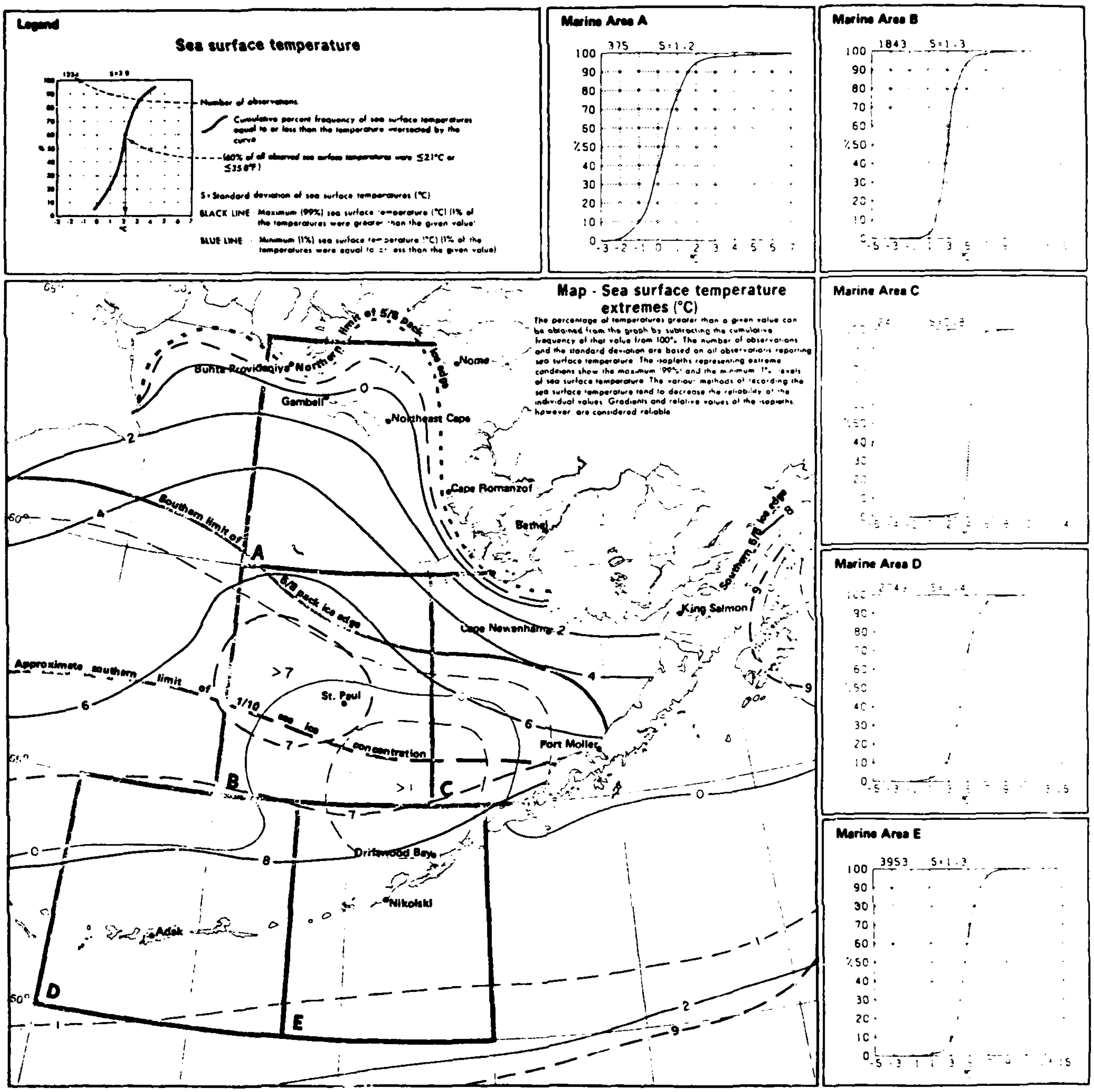

Figure 192. Sea surface temperature extremes, December (from Bering Sea ref. 2).

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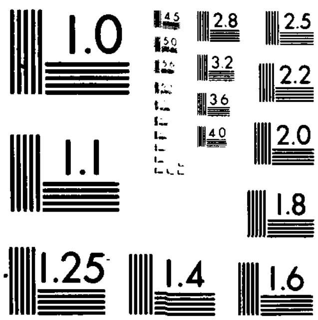

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Appendix D. Recommendations on Data Needs and Future Work

The following is a list of the types of data that are needed in the future. Most were recommended by the authors of the cited references. I suggested a few based by my review of the literature.

Future data needs are:

1. Tidal data - especially along the Beaufort and Chukchi Seas; the amplitude variations along the coast and shelf need to to be determined.
2. Storm surge effects - long-term sea level observations and measurements.
3. Post-storm coastline changes - most susceptible locations.
4. Circulation and currents - seasonal, tidal and wind-driven, especially the surface current of the Beaufort and Chukchi Seas.
5. Bathymetric data - more detailed data on annual changes in bed forms due to ice gouging and other nearshore effects; the effects of storms on basic offshore topography.
6. Sea surface temperature - especially in the winter on the Beaufort and Chukchi Seas.
7. Winter current data - ice-covered flow regime; oceanographic dynamics data are very difficult to obtain with an ice cover.
8. Shelf and nearshore dynamics - interaction and processes.
9. Chemical oceanographic processes.
10. Wave climatology - especially in the Chukchi Sea.
11. Deep water circulation - bathymetric effects, temporary and seasonal variations in flow; role of wind-driven processes.

Appendix E. Suggested Methods for Acquiring Required Data

Data To Be Obtained	Methods
Tidal data	Water level gauges
Storm surge effects	Water level gauges
Post-storm coastal changes	Low-altitude aerial photographs
Circulation and currents	Satellite and aircraft imagery and ship surveys
Bathymetric data	Bottom profiling and photo-bathymetry (for nearshore)
Sea surface temperatures	Temperature and salinity probes
Winter current data	Current meters and temperature and salinity probes
Shelf and nearshore dynamics	Ship surveys and remote sensing techniques
Chemical oceanography	Standard procedures
Wave climate	Standard procedures; radar; CERC procedures
Deep water circulation	Ship surveys

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